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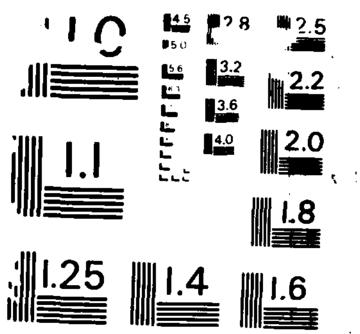

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NCEL
Contract Report

Expert Systems for United States Navy Shore Facilities Utility Operations

ABSTRACT A technology assessment of expert systems as they might be used in Navy utility operations is presented. The report covers hardware and software descriptions and presents applications where computer expert systems can be useful. Some of these applications include design, fault diagnoses, training, data base management, and real-time monitoring. An assessment is given of each application. A description is given of what an expert system is and how it works.

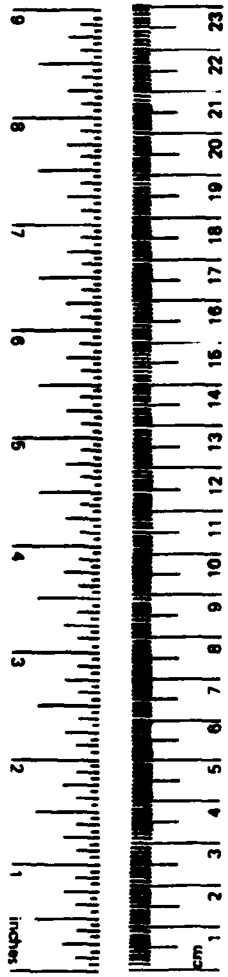
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

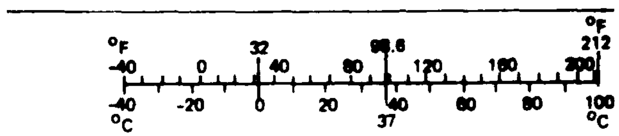
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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A technology assessment of expert systems as they might be used in Navy utility operations is presented. The report covers hardware and software descriptions and presents applications where computer expert systems can be useful. Some of these applications include design, fault diagnoses, training,

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EXECUTIVE SUMMARY

This report presents a technology assessment of one area of artificial intelligence (AI) research; expert systems. The objective is to present a concise overview of expert system technology and examine potential applications for Navy shore facilities utilities operations. Potential benefits and drawbacks to the technology are assessed and future directions for Navy development activities are identified.

Expert systems are emerging as the leading practical application of research in AI techniques. Expert systems are computer-based programs that represent in software form the knowledge of human experts in different fields. Most commonly they are based on "if/then" rules, which in conjunction with facts about a particular subject can logically progress through a given problem to arrive at an appropriate solution.

For this technology assessment, expert systems were reviewed from the perspective of development and implementation of applications on a microcomputer with the attributes of an IBM PC AT. This hardware limitation, the computer configuration most often encountered at Navy installations, serves to define the range of applications that may be addressed. The hardware specification also defines the software choices that are available for future expert system applications. Neither hardware or software problems are foreseen for the Navy due to the rapidly changing nature of the technology in the commercial market. Many application areas are amenable to expert systems written on and for microcomputers.

Expert systems come in all sizes and can be custom-built by vendors, consultants, or in-house personnel, as well as bought off the shelf in generic packages. One of their main attractions is that they often permit the actual users to have a say in the way the systems operate. Such input is usually necessary, in fact, because expert systems are designed to mimic the knowledge and procedures of actual experts.

For the Navy environment, expert systems offer significant attractive features. One primary benefit is that the substantial human expertise that the Navy possesses may become a permanent asset and are not lost upon the expert's retirement. Capturing and preserving the knowledge of skilled individuals for others benefit is an enormous advantage for expert systems. Another benefit for the Navy is that management is continually confronted with a constrained budget and a limited number of personnel. Expert systems, acting as assistants, will help personnel perform tasks more rapidly and with fewer errors thereby increasing the amount of work that can be done. Productivity improvements will be possible for people in such disparate areas as computer programers, facility maintenance, and management.

Another benefit is that as technologically sophisticated equipment is dispersed throughout the various shore facilities, increasingly fewer people are capable of diagnosing and repairing problems. Expert systems can capture current information and make it readily available to workers at many locations, simultaneously. The ability to repair equipment without having to wait for the arrival of a human expert from another location will result in less downtime for equipment.

Many applications have been identified for candidate expert systems. The application areas that are most promising include: fault diagnosis, data base management, and design of buildings or processes. For each of these areas, shore facility-related problems exist that are amenable to expert system technology. Diagnostic and repair expert systems may be created for a range of mechanical and electrical engineering problems including: steam distribution systems, power transformers, refrigeration systems, circuit boards, photovoltaic power systems, and pneumatic and electronic control systems. Design expert systems may be developed for such applications as cogeneration feasibility analysis, energy retrofit of buildings, building renovation, the design of photovoltaic power systems, and the design of passive solar buildings. Data base analysis is emerging as an important area for management support for decision-making. Expert systems may be developed to assist in accessing and using data in areas such as engineering specifications, vehicle fleet management, evaluation of sub-contractor bids, or in the procurement process. Each of these application areas deserves attention for the immediate development of expert systems.

Even though there is reason for considerable optimism for Navy applications of expert systems, management should not be overly sanguine. Expert systems are not a panacea for all of the operations management problems. Expert systems may make mistakes or their knowledge base may be too limited to provide a reasonable answer. Automatic knowledge acquisition will not be possible. Implementation and training issues may assume more significance in terms of effort and management commitment than the actual time required to create an expert system.

It is recommended that NCEL develop several prototype expert systems and field test them at selected shore facilities. The expert systems may be developed through a combination of contractors and in-house personnel. Applications in fault diagnosis, design, and data base management are most promising. Product testing should take place somewhat concurrent with product development so that user input is effectively integrated into the final product. A full field test should be implemented and a complete evaluation of the prototypes undertaken after the field test.

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EXPERT SYSTEMS FOR UNITED STATES NAVY SHORE FACILITIES UTILITY SYSTEMS

1.0 INTRODUCTION AND PROBLEM DEFINITION

Expert systems have emerged as the leading practical application of the techniques developed in artificial intelligence (AI) research. Considerable attention has been devoted by public media to some pioneering and successful expert system applications. For example, Prospector, an expert system devoted to geological exploration, was responsible for identifying a $100 million molybdenum deposit that had been overlooked by geologists (SRI, 1980). Expert systems are also used by chemists as an aid in determining molecular structures, by bankers as a tool to screen loan applicants, and by physicians to help assist the diagnosis of infections. It is clear that expert systems will be applied to an increasing number of tasks in a broad range of fields. One promising area is in facilities or operations management. It is anticipated that expert systems may increase the efficiency of delivery of certain services, reduce the amount of time required for some tasks, and improve the quality of work for areas with high personnel turnover. A technology assessment of the tool and its applicability to Navy shore facilities operations management of utility systems is the subject of this paper.

The Naval Facilities Engineering command (NAVFACENGCOM) is responsible for providing material and technical support for shore facilities, real property, utilities, fixed ocean systems and structures, transportation and construction equipment, energy, environmental and natural resources management, and support of the Naval Construction Force. NAVFACENGCOM reports directly to the Chief of Naval Operations. The NAVFACENGCOM organization is comprised of the following:

- Headquarters
- Six Engineering Field Divisions (EFDs)
- Seven Officers in Charge of Construction (OICCs)
- Nine Public Works Centers (PWCs)
- Three Construction Battalion Centers (CBCs)
- The Naval Civil Engineering Laboratory (NCEL)
- The Naval Energy and Environmental Support Activity (NEESA)

Across the NAVFACENGCOM community there are numbers of individuals with talents specific to the Navy's mission. These individuals are technical experts in fields such as roofing, structural engineering, planning, paints and coatings, etc., and maintain a significant quantity of knowledge regarding Navy applications and procedures. This specialized knowledge is considered essential for the maintenance of fleet readiness and fulfillment of the Navy's mission.

Each of the six EFDs and Headquarters maintains an Engineering and Design Division which is responsible for the design of all shore facilities for the Navy and other Federal agencies. While most of the design is performed by A&E contract, many design projects are too small to contract out within the statutory 6 percent fee limitation and thus are done in-house by EFD personnel. In addition, a certain number of designs are set aside for in-house preparation in order to keep personnel current and to train new employees. Certain specialized designs are accomplished in-house in connection with designated centers of expertise, and as a means of preparation for mobilization.

All of the six EFDs and Headquarters maintains a Planning and Real Estate Division which is responsible for the implementation of the Shore Facilities Planning and Real Estate Management functions. During conduct of this responsibility, real estate, planning, and natural resources data are collected, analyzed, and maintained while various planning, environmental, encroachment and other studies are conducted to provide guidance and document real estate and planning decisions.

Each of the six EFDs and Headquarters maintains a Facilities Management program which is responsible for the identification, operation, maintenance, analysis and procurement of utilities and utility services, assistance to activities in inspections, technical solutions and design services for the maintenance and repair of roofs, exterior and interior surfaces, pavements, underground utilities, corrosion prevention, bridges and railroad structures, the operation and maintenance of transportation equipment, and maintenance of Fleet mooring and waterfront facilities. The inventory lists over 186,000 facilities with a current plant value of approximately $90 billion, a current MILCON increment of $1.6 billion, and current Fleet annual operation and maintenance expenditure of $24 billion.

The nine Public Works Centers provide a full range of mission support to assigned customer activities for various facility planning, design and engineering services, and maintenance functions. These services include the preparation of engineering drawings, facility plans, layouts and design drawings, and the provision, maintenance and repair of utility systems and services. Expert technical advice is codified in design manuals, technical specifications, maintenance and operation manuals, and considerable associated paperwork. Many times the information provided does not capture the rules of thumb and technical insight of the experts whose knowledge is encoded in the paperwork system.

The Naval Construction Battalion Centers support the active and reserve Naval Construction Force (NCF) and special operating units of the Navy. Support is provided by determining equipment and material requirements, procuring and managing material, performing the full range of integrated logistics support functions for the Sealift Program, and storing and maintaining prepositioned war reserve material stocks.

The Naval Civil Engineering Laboratory is the principal Navy research, development, testing, and evaluation center (RDT&E) for shore facilities, fixed surface and subsurface ocean facilities, and for the Navy and Marine Construction Forces. A full range of pure and applied research, development, testing, evaluation and technical consultation is provided to NAVFACENGCOM, Navy, Marine, and other federal agencies. The Laboratory has a full range of acknowledged experts in the technical areas of importance to the NAVFACENGCOM community such as structural engineering, roofing, and utility systems.

The Naval Energy and Environmental Support Activity provides specialized support for the energy conservation program, environmental protection programs, and the broad functional area of Navy Occupational Safety and Health (NAVOSH). An inventory of experts is available to assist field organizations to fulfill their mission. Currently the evolution of energy and environmental problems in the field is growing exponentially while manpower available for assistance is declining. In addition, the transaction time required to evaluate and respond to requests for assistance may preclude a timely response to a field unit's problem.

The scope of activities at Navy facilities performed by NAVFACENGCOM personnel may be referred to as operations management. Within that context it is helpful to focus on utility systems. Broadly defined, operations management of utility systems refers to the provision or delivery of fuel, water, and the operation and maintenance of the many buildings at each shore facility. Thus the scope of this study includes not only heating, ventilating, air-conditioning (HVAC), and plumbing concerns but also painting of buildings, entomology (applied to insect control), training new servicemen, preparation and review of bid specifications, and evaluation of contractor proposals.

The approach for this study was to first review characteristics of expert systems and their usefulness within an operations management context. Next, it was useful to define or classify utility systems operations. Operations were categorized as to a particular application (e.g., fault diagnosis, training or counseling, data analysis, real-time monitoring, management support, or computer assisted design). Subsequently, each operation was further classified according to applicable expert system parameters.

For the study the Navy specified one constraint that served to direct the assessment. A hardware choice, determined by both the configuration of and the availability of machines in use for field activities, limited the machines that could be analyzed to the equivalent of at least an IBM PC AT in terms of computing speed, memory size, and program compatibility. This hardware choice imposes both software constraints and, more importantly, tends to limit the size or complexity of potential applications. While more will be said on these two issues later, it is important to note that large application programs written in LISP, C, or Forth, for LISP or other special environment machines are not considered in this study.

It is recognized that both computer hardware and expert system technology are changing rapidly. Bigger and faster machines, particularly 32 bit machines, are being introduced at prices that were once inconceivable. These machines will begin to appear at Navy installations. Expert system applications may be written on large machines in a variety of compiled formats for delivery on microcomputers. Increasingly complex applications may be considered for expert systems over time. Thus this technology assessment represents a conservative view of potential AI applications for Navy shore facilities. More ambitious expert system applications will undoubtedly evolve for Navy use, though the nature of such systems cannot be determined with any confidence.

The advantages that should accrue to the user of an expert system include:

1. Human expertise fades quickly. Expert systems could conceivably last forever and be updated on a regular basis.An expert in quality control has to be in constant practice to retain proficiency.

2. Enhanced manpower productivity. As workloads increase and budgets are constrained, an expert system provides one means for improving personnel efficiency for a given task.

3. An expert system has portability. The expert system can be in many places simultaneously thus expanding a precious knowledge base to the entire Navy.

4. Documenting human expertise is difficult. Expert systems may be easily documented, including the explanation for arrival at a solution.

5. User friendly. A buzz word but the essence of an expert system is that it removes the user from the operating environment and only addresses that problem at hand, not the problem of how to use the tool (i.e., the computer).

6. Imperfect data is useful. Like a human expert, an expert system can operate with less than the ideal amount of information. The deduction process allows the expert system to arrive at a recommendation.

7. Access to data bases. Data bases are increasingly complex. Easy access to critical data needs is facilitated by "intelligent front ends" to data bases.

However, despite the aforementioned advantages for expert systems, human experts will not disappear. Humans can learn and be imaginative while today's computer "experts" cannot. An expert system will have a narrow focus while managers are often concerned with "broad" issues. Common sense is a key ingredient for a successful manager or expert and today's computers lack the facility to acquire common sense.

2.0 EXPERT SYSTEMS

2.1 Introduction

It is not easy to define either what an expert system is or what one should expect from an expert system. One useful definition is offered by Johnson, "An expert system is a computer system which emulates human expertise by making deductions from given information using the rules of logical inference (Johnson, 1984)." Johnson's definition embodies the "how" of expert systems. One may also wish to consider a definition for the "what" of an expert system. In this context the phrase expert system tends to refer to a particular software architecture, a way of structuring knowledge and program instructions in the computer to facilitate the solution of a wide range of problems. Indeed, expert system software can often be useful for non-expert system applications, while more traditional programming languages may be used for AI applications.

In general terms, an expert system is a problem-solving tool. The computer program makes expertise available to a user who is not necessarily an expert. Expert systems generally consist of the following components (Hewlett-Packard Chronicle, 1985):

- A knowledge base containing information about a particular domain of expertise and rules describing the relationships between pieces of information.
- An inference engine that generates a recommendation by combining the rules and the information from the

knowledge base with user-supplied facts about a particular situation or problem.

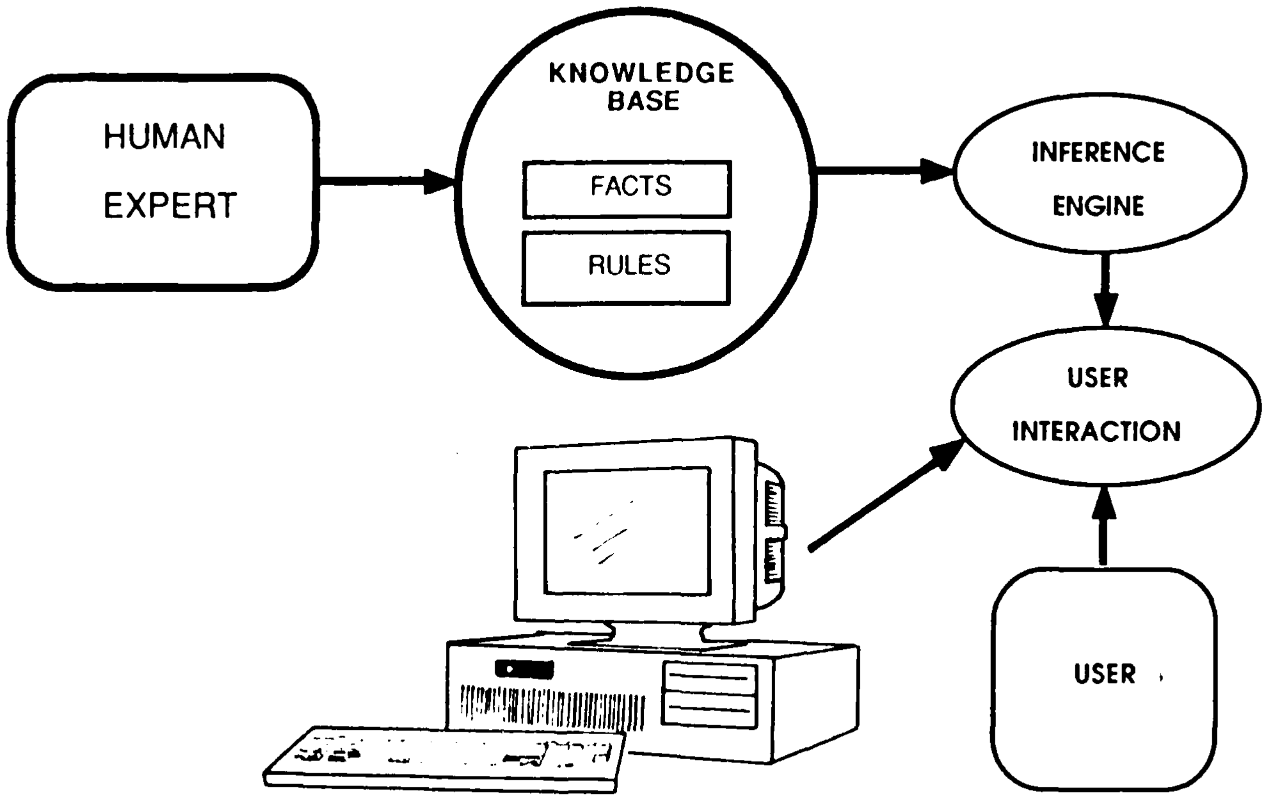
- A user-interactive device, generally a computer terminal, that accepts facts about the situation and transmits to the nonexpert user knowledge in the form of recommendations.

An expert system operates in a manner shown in Figure 1. A human expert(s) is interviewed by a knowledge engineer (i.e., a systems analyst) to determine how a particular problem is solved. This approach is codified in the knowledge base and consists of rules and facts. Generally these facts are represented in a tree-like structure (i.e., a decision tree) with a series of if-then rules. As with human experts, the rules and facts may be ranked by a probability of occurrence given preconditions supplied by the expert(s). The user supplies the inference engine with a number of inputs in response to machine driven inquiries. The queries are structured to guide the user through the problem resolution and have the added benefit of being visible. Also, in most expert systems the user may invoke a "why" or "how" statement to determine why or how the machine has reached a certain conclusion. The machine then presents a "because" or displays the rules that were invoked by the user's interaction.

The interface between user and computer must be carefully designed for efficiency with the intended user group, or the system will be cumbersome to use. The interface is much more than a user-friendly sugar coating, because the expertise of an expert system is actually shared by user and machine--their combined knowledge and experience allows smooth purposeful interaction for solving a

Figure 1

Expert System Operation



problem. The pursuit of a solution begins on common ground shared by the user's knowledge and the computer system's expertise. The computer's expert system then guides the user to it's domain of expertise, performs it's main functions, and translates the results of that expert performance into terms meaningful to the user. There is no generic user. The interface should be aimed at a particular group of users, and then be sufficiently adaptive neither to waste the time of experienced practitioners, nor to confuse beginners.

The explanation facility is an extension of the user interface that allows examination of the inner processes of the expert system. This introspection facility assists during program development, and is probably required even for final implementation of large systems.

Computers work toward satisfaction of goals by using the knowledge-base to try various combinations of its data until the current goal is matched. Blind trial and error searches are unacceptable even for the largest and fastest computers available today. For example, to try a mere 20-factorial combinations in a computing machine capable of a billion comparisons per second would require 77 years, and real problems, even in narrow domains, can easily have far more functionally distinct possibilities. It is knowledge that must supply rules to guide an efficient inference engine through a search process for acceptable solutions, by severely trimming the decision tree to a realistic number of options. Nonetheless, depending on the application, the hardware for expert system implementation can make demands on computer speed and memory.

Although an inference engine is tailored for efficiency with the task at hand, the engine has rather broad reasoning power over the domain of the separate knowledge base. This allows a very flexible organization of the knowledge base. It can include a growing list of facts and rules as new knowledge is obtained from various human experts. It can include heuristic rules used by human experts, even when there is no visible rational justification for such rules. The entire function of the expert program can be altered simply by changing its knowledge base, which is usually easy to understand for both knowledge engineers and experts within the domain. Each item of the knowledge base is only a statement of a fact or a rule, often expressed in a computing language that is quite readable. Program development may be rapid and flexible.

2.2 Software and hardware for expert systems

The following discussion of software and hardware for expert systems is an examination of the current technology. It is important to realize that the computing environment is changing rapidly and that statements made in this report may be superseded within a short time. Therefore, it is probable that in this report the assessment of software and hardware choices is limited to a conservative view of potential applications. Future technology changes, unknown at this time, may expand the possibilities for expert systems well beyond the range presented here.

We have seen the internal structure of expert systems in the abstract. We shall now look at programming languages suitable for expert systems development, then at higher level program development tools like expert system shells, and finally at the hardware required for various size tasks.

Languages developed for representation and manipulation of words and concepts are central to efficient development of expert systems. Many ideas can be expressed by ordered lists of symbols. Manipulation of given lists or generation of new lists, list processing, can "process" ideas much as logic applied to natural language does. Two of the major languages used for AI applications are LISP (LIST + Processing) and Prolog. LISP is a versatile list-processing language that has been favored for AI work in the United States. Prolog, which integrates list processing with internal procedures for the satisfaction of goals, was evolved in Europe and is favored both there and in Japan where it is used for their Fifth-Generation Project. An increasing number of domestic applications, particularly for microcomputers, are being written in Prolog. Most other programming languages (for example, FORTRAN, PASCAL, C, or even BASIC) could be used for expert systems, but development can be cumbersome.

2.2.1 Prolog (*adapted from PC AI Spring 87*)

Prolog is relatively new with a growing number of available commercial aids. Prolog stands for PROgramming in LOGic. It is similar to LISP in its suitability for symbolic processing and its powerful list processing capabilities. In addition, Prolog is often implemented as an interpreted language, making it well suited for AI applications. There are, however, compiled versions in use today. The biggest drawback with the Prolog language is its slow speed;

however, the power and flexibility of Prolog, by comparison with third-generation languages such as Pascal and C, is remarkable.

Prolog's powers reside in its declarative approach to solving problems. A Prolog program operates by providing the computer with a description of the problem to be solved. Thus, to program in Prolog, one performs two general programming tasks. The first task is to specify the facts and rules about objects and relationships. Once this information is provided, you begin the second task--specifying goals for the program to solve. Goals function as questions and are also written in Prolog's simple syntax. For small expert systems, the compact goal-seeking facility of Prolog may form much of an inference engine. The intricacies, and full power, of Prolog need not be used to achieve an acceptable expert system. However, for large expert systems, only programs that efficiently use the capability of the microcomputer can hope to succeed. In this case, Prolog can do an admirable job, but the programming is not done simply.

An increasing number of expert system programs are being written in Prolog, including SOLFIX for the Navy. The reasons for Prolog's popularity include the low price of the software and toolkits, the fact that the software is aimed at the microcomputer arena, and the increasing number of university courses that feature Prolog. While LISP probably is the most popular AI language at this point, Prolog implementations are increasing rapidly.

2.2.2 LISP (*adapted from PC AI, Spring 87*)

The two major specialized list processing languages, LISP and Prolog, are probably capable of similar levels of performance. LISP has evolved over two decades, and has an array of programming tools and expert system shells available to assist expert system programming. The power and flexibility of LISP lies in the radical departure of the language from traditional methods of numeric processing.

LISP programs work with symbols, thus making it a suitable language for many AI applications, from theorem proving to natural language processing. Since most implementations of LISP are interpreted and the program code and data are interchangeable, it is possible to create programs that are self-modifying. That is, programs can be used to create other programs, or to modify themselves. This self-modifying concept is the basis for the science and art of writing programs that have the capacity to learn.

The LISP language is general enough to be used for any application. In fact, LISP is a very good language to use as a learning tool. Many schools and universities now use LISP to teach beginning computer students the fundamentals of programming and computer science. Since the language is interactive, it is easier to write and test more complex programs than for more conventional languages. The major drawback to the language is its slow execution speed and its large demands on memory.

Many dialects of LISP are available for a wide range of computers. Some of the more popular versions include IQLISP, INTERLISP, XLISP, MACLISP, and FranzLISP. Obviously, LISP is not a static language, a fact that is reflected in its constant evolution since its creation. Of course, the differences between dialects can create problems among programmers, especially for programmers who attempt to write LISP programs that will run on different computers. However, a standard dialect known as Common LISP has been developed to alleviate some of the diversity. This new standard is the result of contributions from a national committee of LISP experts. The Common LISP standard now newly applied, should have very positive effects on the growth and use of the language.

2.2.3 Smalltalk (*adapted from PC AI, Spring 87 and Dr. Dobbs Journal, September 1987*)

The Smalltalk environment is something of a departure from the more established AI languages LISP and Prolog. Smalltalk is more than just an object-oriented programming language; it is a complete environment for programming and using a computer. The language itself provides facilities for data abstraction, message-sending, object classification, and interactive development. Perhaps most important, Smalltalk provides a complete programming development toolkit. Because of these programming development features, Smalltalk is often used for rapid prototyping, expert systems development, and other AI applications. The built-in graphic interfaces make it an ideal system for developing good user/program interfaces. In fact, many Smalltalk models have been built specifically to study human/machine interfaces.

Considering the power inherent in the Smalltalk environment, you might be wondering why more programmers are not using the language. The main reason: For many years, programming in Smalltalk was reserved for Xerox employees, since no other commercial systems were available. Also, the graphic windows require a large memory that has not been available until recently on microcomputers.

However, Smalltalk-80, the most recent version of the language, is available for several machines and in several forms that support multi-windowed environments. These windowing capabilities are especially useful for inspecting or extending the system. Some powerful versions of Smalltalk-80 are also up and running on popular microcomputers such as the IBM and compatibles and the Macintosh. For example, Digitalk's Smalltalk/V programming tool is a bit-mapped implementation of a substantial subset of Smalltalk. It is aimed primarily at the AI development market with two strong features: object orientation and a rather complete Prolog compiler. Smalltalk/V also has extensive graphics capability including animation. Smalltalk/V differs from previous Smalltalk implementations in that is requires less than a half a megabyte to run the program making it well within the range of most microcomputers.

Even though it was held up at the starting gate for many years, Smalltalk-80, with is exploratory programming system and toolkit approach to software development, still appears to be a strong contender for AI-language popularity. With the addition of such products as Smalltalk/V, microcomputer applications will appear with increasing frequency.

2.2.4 OPS (*adapted from PC AI, Spring 87*)

OPS, which stands for Official Production System, was first developed in the mid 1970s. The language evolved as a research tool in psychology for understanding human memory and cognition. To understand and use the language, it is helpful to have some background in the production-system model (i.e., rule-based systems) of computation. Production-system techniques are useful when the knowledge related to a programming problem occurs in a natural rule structure. There are actually quite a few different versions of OPS running on computers from mainframes to micros. The two important and most widely used ones are OPS5 and OPS83.

The OPS5 version is usually implemented as an interactive, general programming environment. The generality of OPS5 makes it a difficult language to classify in terms of application use. OPS5 supports a simple inference engine as well as representations for If/Then rules and forward chaining, making it a useful tool for developing rule-based expert systems. Most versions of OPS5 are actually implemented in LISP and provide facilities for graphics, windows, and programming development tools. To run most of these implementations, you need a LISP interpreter.

OPS83, on the other hand, is written in C. The strength of this version is its portability, which provides the programmer with a good tool for developing and delivering expert systems on other machines. Unfortunately, since OPS83 is compiled and does not have built-in rule interpreters, you must always recompile the system whenever new rules are added. This takes away the ease of developing programs and slows down the process of testing new ideas. On a more positive note, OPS83 programs will certainly execute much faster than OPS5 programs because they are not interpreted at run-time.

For those interested in using OPS5 or OPS83 but are unsure about what you can do with it, here is list of successful types of applications that have been developed with the language:

- Expert system to configure complex computer systems
- Electrical system diagnostics
- Strategic game programs such as chess
- Heuristic problem solving

Actually, OPS is well suited for any type of rule-based application such as general expert systems. Overall, the basic syntax of either version is relatively easy to learn. A major drawback to implementing OPS has been the price of the software and the hardware. This situation is now changing. There are now implementations of OPS for IBM PCs and Macintoshes, which should help to promote the language.

2.2.5 Development Tools

The development of expert system interfaces, knowledge representations, and inference engines using LISP or Prolog is no easy matter. Expert systems development software is available for various computers and operating systems to aid with the mechanics. A variety of development tools are presented in Tables 1 and 2. The personal computer tools range from simple Prolog extensions for expert systems (e.g., Apes, $275), to expert system shells with induction ability (e.g., Expert-Ease, $2,000, VP Expert, $100), to expert system shells with hands-on instruction included (e.g., M1, $5,000), to a complete system for deduction of rules from decisions (e.g., Rulemaster, $60,000). The full-featured expert system

TABLE 1
Representative Expert System Development Software
for Personal Computers

Tool	Source	Machine	Price	Comment
Apes	Logic Based Systems, London, UK	IBM-PC	$225	Micro-Prolog logic with extended expert systems features
Expert-Ease	J. Perrone & Assoc., Inc. San Francisco,	IBM-PC 128 Kbytes CA	$2,000	For small expert systems. Induction of rules.
Rule-master	Radian Corp. Austin, TX	IBM PC Unix 4.2	$50,000	Extended induction from decisions.
Turbo Prolog	Borland Int'l Scotts Valley, CA	IBM PC	$100	
1st Class Fusion	Programs in Motion, Wayland MA	IBM PC	$1,295	Multi-function programming and application environment
Exper Interface Builder	ExperTelligence Santa Barbara, CA	MacIntosh	$300 + $1000	Graphic oriented editor for LISP
Intelligence/ Compiler	Intelligence Ware, Los Angeles, CA	IBM PC	$990	Development environment
Smalltalk/ V	Digitalk, Inc. Los Angeles, CA	IBM PC	$100	Rapid Proto-typing
Arity Standard Prolog	Arity Corp. Concord, MA	IBM PC	$95	Clocksin and Mellish Standard
Trans LISP	Solution Systems Norwell, MA	IBM PC	$95	LISP Interpreter
Active Prolog Tutor	Solution Systems Norwell, MA	IBM PC	$65	Prolog Learning

TABLE 2
Representative Expert System Development Software for Larger Computers

Tool	Source	Machine	Price	Comments
Arby	Smart Systems LcLean, VA	Any using LISP	$9,000	Shell for diagnosis of- electrical equip.
ART	Inference Corp. Los Angeles, CA	LMI Lisp, Symbolics	$60,000+ 3,600,	Gen. purp. exp. sys. dev. tool
DUCK	Smart Systems McLean, VA	Any using LISP	$6,000	Logic-based prog. language running within LISP envir.
K:Base	Gold Hill Computers, Cambridge, MA	Symbolics	$5,000	Networking through IBM-PC's
KEE	IntelliCorp Menlo Park, CA	Most LISP workstations	$60,000	Gen. purpose exp. sys. dev. tool
KES	Software Arch. and Engineering Arlington, VA	VAX, Apollo, Symbolics IBM-PC, others	$23,500	Gen. purpose exp. sys. dev. tool
LOOPS	Xerox PARC Palo Alto, CA	Xerox 1100	$300	Object-oriented prog. language (no support)
OPS5	Digital Equipment Corp Hudson, MA	VAX	$10,000	VAX AI prog. environment.
Plume	Carnegie Group Pittsburgh, PA	SLR+ for UNIX	$35,000	
Sage-2	ICL London, UK	ICL VME/2900 (for VAX, $12,000)	$22,500	Mainframe shell emphasizing ease of use
SLR+	Carnegie Group	most LISP workstations	$70,000	Gen. purpose exp. sys. dev. tool
S1	Teknowledge Palo Alto, CA	Xerox 1100, 1108, soon VAX	$50,000+	Gen. purpose exp. sys. dev. tool

development tools for LISP workstations (e.g., ART, KEE, SRL+, and S1, selling above $50,000) offer enormous resources for expert system development, but the application must justify the high costs of development hardware and software, and must be able to support expensive delivery vehicles. LOOPS, furnished by Xerox at a nominal fee for its 1100 machines, but not supported, is an alternative.

2.2.6 Expert System Shells

Programming languages such as LISP or Prolog offer great flexibility to the expert system builder but generally fail to provide guidance on how to represent knowledge or mechanisms for accessing the knowledge base. An alternative to programming languages is an expert system shell. Expert system shells are sophisticated development tools that consist of a programming language integrated into an extensive support environment. A shell may be thought of as an empty expert system, that is an expert system without its domain-specific knowledge. An expert system shell offers little flexibility, since the user must use the control scheme defined by the existing inference engine. However, the shell offers the advantage that the programmer need not be knowledgeable about programming languages but only understand the operations of the shell itself. In many cases the shell is quite easy to understand and use. Many microcomputer applications are currently being implemented on shells because of the ease of creation and short time required for development.

In the technical literature and in common usage, it seems, shells can be anywhere on a continuum from interpreters of relatively simple languages to very elaborate development environments. However, they all have their purposes and strengths, and can possibly complement each other by being used at different times in a project's lifecycle. A set of common minimum features for shells include: (a) a knowledge representation scheme, (b) an inference or search mechanism, (c) a means of describing a problem, and (d) a means of determining the status of a problem while it is being solved (Citrenbaum, et al, 1987). Shells can be extended to tools that act as interpreters, compilers, or symbolic debuggers. Many shells also offer the ability to communicate with popular spreadsheet and data base software thus enhancing the potential knowledge base considerably.

One approach used by shells is referred to as induction. Inductive shells can build a system from a statement of knowledge and its relationships. Products such as ExpertEase, EXFAULT, and VP Expert fall into this category (see Table 3). With these shells the user states the knowledge used to arrive at conclusions. These products require a table of values for evidence and the resultant conclusion, and produce an optimized query tree, implicitly determining intermediate nodes.

Other shells take an explicit set of rules and goals, and conduct the user interface in such a way as to determine the facts required to satisfy the goals. With Insight 2+, for example, the knowledge takes the form of IF-THEN rules. Some shells perform analyses to optimize the dialog and allow (or require) the user to exert control over operations.

Also called expert system shells are the more elaborate systems available on symbolic computing hardware and powerful minicomputers, such as ART or KEE. Some observers would say that expert system shell is too limited a name for these tools, and that a term like knowledge programming environment should be used.

Thus it is evident that the term expert system shell refers to a broad range of products with a variety of functions and features. The four basic elements (i.e., knowledge representation, inference mechanism, problem description, and status determination) are found to varying degrees in all shells. However, the usefulness of the shell depends in large measure on the requirements and skill level of the user or developer. A shell may be an appropriate tool during the lifecycle of an expert system, particularly in the early stages of prototype development.

The commercial market for expert system shells is growing rapidly. In Table 3 a comparison of 27 shells shows the breath of features in shells currently available. Prices range from $100 to $7,500 and the features vary from shell to shell. Explanatory text accompanies the table.

2.2.7 Hardware

The computer hardware available to most workers in the Navy utilities systems area is modest in speed and memory. Table 4 lists pertinent properties of a few classes of microcomputers. Only the middle two entries are readily available to workers in the Navy today, though the fast 32-bit machines should dominate the professional personal computer market within a few years.

TABLE 3

EXPERT SYSTEM SHELLS

PRODUCT	VENDOR	REQ'D MEMORY (BYTES)	REASONING METHODS: FWD CH	BK CH	INDUCTIVE	RULE BASED	EXAMPLE BASED	TEXT CAPABILITIES: AUTO DISPLAY	DISPLAY ON REQUEST	PROBABILITY CALCULATION: MODE	METHOD	THRESHOLD	DATA INTERFACES: R base	dBASE	1-2-3	ASCII	REAL TIME	SOURCE LANGUAGE	SOURCE CODE PR	PRICE
[illegible]S	California Intelligence	200K	X	X		X		X	X	X	X	X	X	X	X	X	X	LISP or C	X	$395
[illegible]a Generator	Experience in Software	256K						X					1	1				Pascal		$195
[illegible] Advisor	Expert Systems, Intl	348K	X	X		X		X	X	2	2	2		1	X		X	PROLOG	X	$895
[illegible] Frame Engine	Expert Systems, Intl	640K	9					X	X	2	2	2		1	X		X	PROLOG	X	$895
[illegible]	Expertech, Ltd	512K	X	X	X	X	X	X	X	1	1	1	X	X	X	X	X	PROLOG and C	X	$1,250
[illegible] 3.2	EXSYS, Inc	256K	X	X		X			X	X	X		1	1	1	1	1	C	X	$395
[illegible]-C	General Research Corp	640K	3				X		X				1	1	1	1	1	FORTRAN		$1,900
[illegible]	Gold Hill Computer	5M 10M	X	X		X			X		X	X		X	X	X		LISP		$7,500
[illegible]	KDS Corp	512K	X	X	X		X		X						X		X	Assembler	X	$1,495
[illegible]ge Pro	Knowledge Garden Inc	512K	X	X		X	X	X	X	X	X	X				X		Turbo Pascal		$495
[illegible]ge Master	Knowledge Garden Inc	512K		X	X		X		X						X	X		Knowledge Pro		$99
[illegible]	Level Five Research	512K	X	X		X		X	X	X	X	X		X	X	X	X	TURBO Pascal	X	$685
[illegible] Expert	McGraw Hill Book Co	128K		X		X		X	X						X	X		TURBO Pascal		$50
[illegible]	Micro Data Base Systems	640K	X	X		X	X	X	X	X	X	X	X	X	X	X	X	C	X	$6,500
[illegible] Object	Neuron Data	640K	X	X		X4		X	X	X	X	X		X	X	X	X	C	X	$5,000
[illegible]	Personal Computing Engineers	256K	5			X	X	X	X		X	X		X	X	X	X	dBase	X	$75
[illegible] FW2	Personal Computing Engineers	640K	5			X	X	X	X		X	X		X	X	X	X	FRED	X	$100
[illegible]	Programs in Motion	256K	X	X	X	X	X	X	X	X	X	X		6	X	X	X	Pascal Assem	X	$495
[illegible] Fusion	Programs in Motion	512K	X	X	X	X	X	X	X	X	X	X		X	X	X	X	Pascal Assem	X	$1,295
[illegible] Master	Paduan Corp	640K	X	X	X		X	X	X	X	X	X		X	X	X	1	C		varies
[illegible] E	SIL	640K	X	X		8		X	X				X	X	X	X	X	C	X	varies
[illegible] Expert	Softsync Inc	256K			X		X		X							X		FORTH	X	$200
[illegible]	Software A&E Inc	512K	X	X					X	X	X		X	X	X	X	X	C	X	$4,000
[illegible]	Teknowledge Inc	384K	X	X		X		X	X	X	X	X	X	X	X	X	X	C	X	$5,000
[illegible]	Texas Instruments	512K	X	X		X			X					X	X			Scheme	X	$495
[illegible]	Texas Instruments	640K	X	X		X			X					X	X			LISP	X	$2,950
[illegible]	Expertack Software, Intl	256K	X	X	X	X		X	X	X				X	X	X		C	7	$100

[1] Through external link
[2] Programmable
[3] Analogic
[4] Objective-based
[5] Pattern recognition
[6] Through ASCII
[7] Includes run-time license
[8] Semantic-based
[9] Frame based

SOURCE: *PC World*, July 28, 1987

A List of Definitions of Accompany Table 3

Forward chaining: Forward-chaining logic begins with known facts and works forward through the set of rules to determine the implications. It identifies all rules whose "if" portions are true and uses the "then" portions to find other rules that are also true.

Backward chaining: Backward-chaining logic begins with the desired goal and works backward to determine the conditions necessary to meet that goal. The program forms a hypothesis and works backward to prove it, seeking the rules whose "then" portions match the "if" portion of the rule that satisfies the goal.

Inductive reasoning: The inference of a generalized conclusion from particular examples. Examples of past decisions and their results are programmed into the computer, which examines this information and applies it to a new situation, using the examples to formulate its own conclusions.

Automatic display: Does the program automatically display the terms and rules it has used?

Display on request: Will the program explain its reasoning upon request? Some programs will ask questions such as, "Would you like to know how I arrived at that conclusion?" while others make the information available through function keys.

Choice of mode: Some programs will allow the user to choose the mode of calculating the probability that a conclusion is correct.

Choice of method: After the user selects the mode, some programs will allow the selection of a method for indicating the probability of the conclusion. Probability can be indicated in a variety of ways, including scales and percentages.

Choice of threshold: Some packages allow the user to set a threshold of certainty for a conclusion.

Rule-based: Rule-based systems extract all the relevant knowledge about a problem from an expert and express it in the form of if-then rules. The system asks questions to determine if the premise of a rule is true. If so, the conclusion is also true.

Example-based: Example-based systems are best suited for problems for which there are existing records, because the records supply the results of several previous cases. These systems work by finding matches between the case at hand and those previously entered in the knowledge base.

Data interface: Can the program accept files from popular data base and spreadsheet packages? Can it interface with an assembly language or machine code in order to perform a routine? Can it interface directly with a measuring/metering device, such as a thermometer, and then assimilate the data?

Source code protection: Does the program provide source-code protection for any of the routines the user may write? This is desirable to prevent the user from modifying the system.

TABLE 4
Characteristics of Available Microcomputers

	CPU chips	Typical Op. Sys.	Clock	RAM	Price
8-bit machines (obsolete)	8080 Z80	CP/M	2-6 MHz	64 K	<$1000
16-bit machines*	8088 8086	MS-DOS	4-8 MHz	256 K	$1000 to $5000
advanced 16-bit machines	68000 80286	UNIX	6-12 MHz	1-4 M	$1800 to $30,000+
32-bit machines	68020 80386 32051	UNIX	10-30 MHz	1-Mbytes	$3000 to $30,000+

K = 1024 bytes
M = 1024 x 1024 bytes
* Machines found commonly at Navy installations

Table 5 lists some LISP workstations and minicomputers with good supporting software for AI software development. The abilities of the LISP machines are considerable, but their widespread adoption requires a system delivery vehicle costing over $10,000, together with the availability of a wide range of applications software. Machines that cost about $30,000, dedicated to particular tasks, could only be purchased by a base with a high demand for expert system applications.

The capabilities of any machine limit its utility for expert system implementation. The programming languages used for expert system development, like LISP or Prolog, use memory voraciously while trying to satisfy goals. One rough guide is that 1 Kbyte of memory is needed for each rule in the knowledge base, unless a

TABLE 5
Representative LISP Workstations
and Minicomputers for AI Applications

Manuf.	Machine	Price	Support
Digital Equipment Corp.	DEC-10*	$1.5-3 million	Mainstay of Prolog development
	Micro-VAX	$35,000	With LISP and OPS5 useful for expert systems
Tektronics	4404	$15,000	Economy AI workstation with Smalltalk. Franz LISP, Prolog avail.
Texas Instruments	Explorer	$65-80,000	Medium performance, AI workstation.
Lisp Machine, Inc.	Lambda	$70,000	High-performance LISP workstation, with full range of program development tools.
Symbolics	3600 series	$60,000 to $100,000+	High-performance LISP workstation, with full range of program development tools.
Xerox	1100 1108	$45,000 $25-50,000	Medium performance, with full range of program development tools.

*No longer available

machine-language compiled program is used in the delivery vehicle, in which case 250 bytes of memory per rule may be sufficient. Such rules of thumb are extremely rough, because the memory space required during execution of an expert system depends on the complexity and depth of search as well as on the number of rules. We can extend the guidelines somewhat, representing the required memory capacity as proportional to the number of expert system rules to some power n. Figure 2 shows the results for n = 0.5, 1, and

RULES OF THUMB FOR MEMORY REQUIREMENTS OF EXPERT SYSTEMS

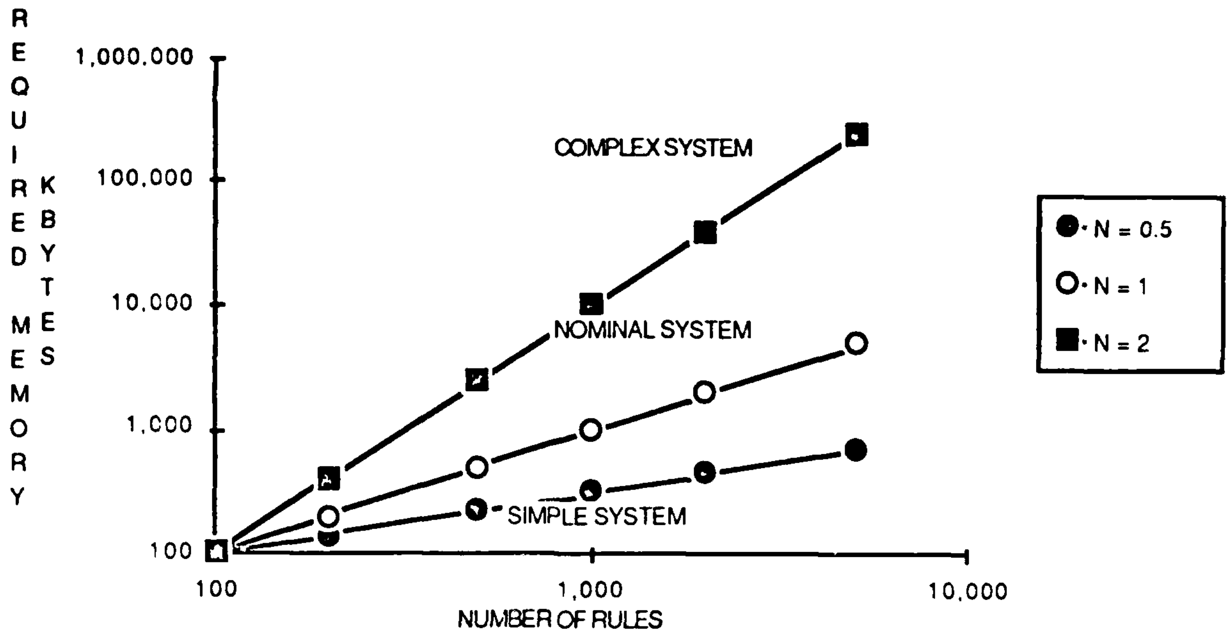


Figure 2

2, corresponding to simple rules with little interaction, rules with average complexity, and highly complex rules with strong interaction. The exponent would be determined from experience with particular types of expert systems. The formula for determining the required memory is:

$$(\text{REQ'D Memory}) = 100 \text{ Kbytes} * \left(\frac{\text{No. of Rules}}{100}\right)^N$$

System implementations on 128 Kbyte memory personal computers seems to support somewhat over a hundred rules, in agreement with the above guidelines. There is a World Health Organization eye care expert system for use by paramedics in the field, supporting 131 rules in BASIC on an Apple II with 128 Kbytes of memory. A small 150-rule subset of the British Nationality Act executes on an IBM-PC with 128 Kbytes of memory. A diesel locomotive maintenance program, CATAS-1, written in FORTH and exceeding 550 rules executes on a microcomputer. If an expert system can be segmented into small sub-experts that interact only slightly, each sub-expert, resident on floppy disk (or preferably on hard disk, for quick access) can support the maximum number of rules. Clearly, useful expert systems can be implemented on microcomputers with as little as 128 Kbytes of memory. With enhanced memory, say to size of 640 Kbytes, larger programs become feasible. For example, SOLFIX, a solar hot water diagnostic advisor developed for the Navy, supports over 300 highly interacting rules utilizing two levels of heuristics, on a 512 Kbyte microcomputer.

Speed of execution is another limitation of computers. Speed in computers comes at a high price, as shown in Table 6. For this example, each factor of ten in computer speed increases cost by a factor of seven for the complete machine. Small expert systems, or systems segmented into almost independent sub-experts, can execute with acceptable response speed even on general-purpose microcomputers. Larger systems may require faster and more expensive computers, perhaps even AI workstations optimized for LISP or Prolog. In some cases, larger expert systems may be run overnight on a microcomputer, leaving good documentation of what the system accomplished.

It is a complex effort to evaluate these tools for all Navy utility systems applications. The high-priced microcomputer tools are most

TABLE 6
Approximate Speed for
Some Prolog Implementations

CPU	Prolog	Op. Sys.	Speed*	Machine Cost
16-bit 8088	micro-Prolog	PC-DOS	240	$1,000
32-bit 68000	NIP	UNIX	2,500	$15,000
--	Lisp Machine	LMI-Lambda	20,000+	$70,000

*Approximate speed in logical inferences per second

useful for quick development of expert systems with large market potential, or for particular applications where speed of development is paramount. Small systems with simple interfaces can be written in LISP, Prolog, or some of the shells without excessive effort. Larger microcomputer-implemented expert systems, or ones utilizing complex graphic interfaces, can probably benefit from an appropriate expert system shell. For near-term applications in Navy utility systems applications, the less expensive development tools for microcomputers will be the most useful.

In summary, it is clear that expert systems implemented on powerful LISP workstations can handle large reasoning tasks in complex domains of knowledge. Sixteen-bit microcomputers with 256 Kbytes of memory can support about 250-rule expert system segments in LISP form, and as many as 1000 rules in machine-language form if the rules are not overly complex or tightly interacting. Newer machines, typical of those to be purchased in the next five years, support several megabytes of memory and are faster, allowing a few thousand rules per sub-expert segment, but execution could be slow for large systems. Expert system shells are available, allowing expert system development to concentrate on acquisition and codification of expert knowledge rather than the mechanics of programming.

3.0 APPLICATIONS FOR EXPERT SYSTEMS

3.1 Introduction

Determining a proper or appropriate application for an expert system is a complex task. Indeed, it is useful to consider the effort as a tool searching for a problem. Because the tool is powerful and has attractive positive features, one may attempt to force fit applications. Such an approach will obviously be inefficient, but rejecting the tool outright is not an enlightened approach either. Thus a methodology for selection of applications is considered here that may be employed for determining where expert systems may be deployed.

Expert systems are useful when there are either knowledge bottlenecks or resource constraints in the organization. Conditions that lead to a favorable environment for the creation of an expert system include:

- a key individual is in short supply;
- manpower shortages limit the number of tasks that can be performed;
- many factors impinge on decision-making;

- performance of the average practitioner is far below the expert;
- funding constraints limit sub-contracting ability;
- in-house expertise may become unavailable in the future;
- expertise is expensive and/or hard to get; and
- payoff is high if more experts were available.

Within the context of Navy shore facilities it is helpful to categorize types of operations that take place. For instance, a particular operation may fall within one or more of the following broad categories: fault diagnosis, training or counseling, data analysis, real-time monitoring, management support, data base management, or computer assisted design. Each of these areas encompass problems that may be amenable to an expert system application yet each will differ according to the way problems are solved within each domain. Further, the complexity of the problems will differ widely thus affecting the appropriateness of tasks for expert system development.

One example expert system being developed for Navy shore facilities is a diagnostician for problems in solar water heaters. The nature of the task is analysis. The knowledge domain is largely predefined (i.e., there are a finite number of known failure modes for solar water heaters). The nature of the knowledge is changing only slowly as system configurations adopt new components. Finally, the mode of operation is interactive (i.e., the repair person queries the machine for recommendations). The prototype system appears to work well as an efficient diagnostician (Gustinis, 1987)

3.2 Application Determination Methodology

The effort to identify applications areas for expert systems within the Navy shore facilities arena follows a methodological approach. For each category (e.g., fault diagnosis), problems were identified that were representative of activities that may occur within the shore facilities operation. These problems were then evaluated according to nine criteria that are judged to be useful determinants of expert system applicability. The evaluations were scored on a one-to-ten basis and then summed for a weighted score. The problem areas were then sorted and ranked according to the numerical score. Table 7 shows the results of the ranking process. Explanation notes at the bottom of Table 7 are provided for the criterion used to evaluate each problem. Appendix A contains a more in-depth description of Table 7.

It is important to recognize that the ranking methodology developed for this technology assessment has not been employed before. It is believed that the approach is realistic and considers the important expert system issues and that the results are credible on a relative basis. However, important subjective determinations were incorporated into both the evaluation and the ranking model and other users may justifiably question some assumptions. Expert systems are a new field and methodologies to evaluate their usefulness are only now being developed.

Another critical assumption is incorporated into the rankings in Table 7. The evaluations of the problem areas were done from the perspective of developing and implementing an expert system on a personal computer with the characteristics of an IBM PC AT. By

TABLE 7

POTENTIAL EXPERT SYSTEM APPLICATIONS
CRITERIA WEIGHTING FOR NAVY SHORE FACILITIES UTILITIES OPERATIONS

[illegible]	1 ESTIMATED TASK DIFFICULTY	2 ESTIMATED PROGRAMMING DIFFICULTY	3 IS TASK CRITICAL	4 EXPERT REQUIRED AT SEVERAL LOCATIONS	5 HUMAN EXPERTISE BEING LOST	6 HUMAN EXPERTISE COST	7 SYSTEMATIC METHODOLOGY	8 PROBLEM STAND ALONE	9 CURRENT COMPUTER USAGE	10 WEIGHTED TOTAL NOW	11 POTENTIAL WITH COMPUTER KNOWLEDGE
[illegible]	4	2	3	3	2	2	1	1	1		
DESIGN BUILDINGS PROCESSES											
[illegible] FEASIBILITY	7	10	7	5	8	8	7	6	7	96	96
[illegible]	7	10	4	8	4	6	7	4	6	81	81
[illegible] RENOVATION	7	10	8	7	5	6	7	5	3	81	84
[illegible] DESIGN	5	7	4	4	5	6	7	6	7	72	72
[illegible] SYSTEM DESIGN	4	6	4	3	3	8	8	9	7	72	72
[illegible] DISPOSAL	6	9	7	4	3	6	7	6	3	71	74
MECHANICAL SYSTEMS DESIGN	6	9	7	3	3	6	4	2	7	68	68
[illegible] SYSTEMS DESIGN	6	9	7	3	3	6	4	2	7	68	68
WATER [illegible]	6	9	7	3	3	6	7	6	3	68	71
[illegible]	8	40	8	3	3	8	6	4	7	24	24
[illegible] SUPPLY	8	40	8	3	3	8	6	4	7	24	24
FAULT DIAGNOSIS											
[illegible]	5	7	5	7	3	4	7	7	3	70	73
[illegible] DISTRIBUTION	6	9	7	8	8	8	7	7	2	65	100
[illegible] SYSTEMS	4	6	4	3	2	7	7	8	4	63	63
[illegible] FORMERS	6	9	8	9	4	5	8	8	2	59	94
[illegible] SYSTEM	5	7	8	9	4	5	8	7	2	56	92
[illegible] CONTROL SYSTEM	5	7	8	8	4	4	8	8	2	52	88
[illegible] CONTROL SYSTEM	5	7	8	8	4	4	8	8	2	52	88
[illegible]	3	4	3	3	5	4	6	4	3	49	52
[illegible] BOILERS	3	4	8	8	2	3	7	6	2	41	76
[illegible] HEATERS	5	7	3	5	2	9	7	7	2	32	68
[illegible]	5	7	3	8	2	4	5	8	2	30	66
[illegible] EXCHANGERS	4	6	3	9	3	2	5	6	2	28	64
[illegible] HEATERS	2	3	3	8	2	2	8	8	2	26	61
[illegible]	4	6	3	7	2	2	7	7	2	23	59
[illegible] SYSTEMS	8	40	4	5	2	9	5	4	6	16	16
[illegible]	4	6	3	8	2	2	5	7	1	9	59
ENHANCING CURRENT TRAINING AND COUNSELING METHODS											
[illegible] ATION	6	86	3	7	7	7	7	7	8	87	87
[illegible]	4	6	3	9	4	2	7	7	3	67	70
[illegible]	4	6	3	9	3	3	7	6	3	66	69
DATA BASE ANALYSIS/MANAGEMENT SUPPORT											
[illegible] SPECIFICATIONS	7	10	7	6	5	7	7	7	6	91	91
[illegible]	6	86	7	8	5	5	7	7	4	90	90
[illegible] CONTRACT BIDS	8	86	5	7	5	6	7	7	5	84	84
[illegible] COST EST	6	86	5	7	5	8	7	7	5	84	84
[illegible]	7	10	7	7	4	4	6	4	3	76	79
[illegible] MAINTENANCE	3	4	8	8	2	3	7	7	3	75	78
[illegible]	5	7	5	6	2	5	7	8	5	73	73
[illegible]	5	7	5	7	3	5	7	5	3	70	73
[illegible]	5	7	3	6	2	5	5	8	4	64	64
[illegible]	5	7	3	6	2	3	5	5	4	57	57
[illegible] NETWORK	7	10	9	8	5	7	2	4	2	56	91
[illegible]	2	3	2	6	2	3	5	8	3	49	52
SOFTWARE SUPPORT											
[illegible]	7	10	3	3	4	8	4	7	9	70	70
REAL-TIME MONITORING											
[illegible] ATION	8	40	9	8	5	7	2	4	2	0	35
[illegible]	9	70	5	6	5	8	8	5	9	23	23

Notes to Table 7

Column (1), ESTIMATED TASK DIFFICULTY.: Estimated difficulty of the problem for resolution by a human expert. A rank of 1 is an easy problem and a rank of 10 is a very difficult problem.

Column (2) ESTIMATED PROGRAMMING DIFFICULTY.: Estimated programming difficulty. Column 2 is linked to column 1. A rank of 1 is easy and a rank of 10 is difficult. The more difficult a problem is for a human expert, the more likely it is that a problem is difficult to program. The criterion is very heavily weighted, particularly after a rank of 8. The weighting factor attempts to account for the difficulty of programming the problem on a microcomputer.

Column (3), IS TASK CRITICAL: This is a determination as to whether the solution of the problem is critical to the operation of a facility or performance of a job. A rank of 1 indicates that the problem is not critical and may often times be ignored while a rank of 10 suggests extreme urgency in solving the problem. This area can be very subjective but it is useful to note that the perspective is from the normal operation of a facility in which the problem may occur. Emergency conditions are considered abnormal and are not included in the ranking.

Column (4), EXPERT REQUIRED AT SEVERAL LOCATIONS: Some problems are repetitive and are found at many locations while others are regional or local in nature. A rank of 10 says that the problem is ubiquitous while a rank of 1 indicates that there are few locations where the problem exists.

Column (5), HUMAN EXPERTISE BEING LOST: Expertise is a precious commodity and human knowledge and ability is often lost because of transfers, death, or retirement. A rank of 10 indicates that expertise is being lost irretrievably while a rank of 1 indicates that experts are plentiful.

Column (6), HUMAN EXPERTISE COST: The cost of an expert will influence the desirability of an expert system. A rank of 1 indicates that expertise is inexpensive and may in fact be commonplace while a rank of 10 suggests that expertise is virtually unobtainable at any price.

Column (7) SYSTEMATIC METHODOLOGY An accepted systematic methodology for solving the problem is a useful criteria for judging the applicability of an expert system. A rank of 10 indicates that there is complete agreement among experts upon one approach for solving the problem. A rank of 1 indicates that the problem is not amenable to a systematic approach.

Column (8) PROBLEM STAND ALONE: If the problem can be isolated from a system, then the problem is often easier to define and solve. A rank of 10 indicates that the problem is isolated and that the problem is identifiable. A rank of 1 suggests that finding the problem area is extremely difficult to define.

Column (9) CURRENT COMPUTER USAGE: Do people who attempt to solve the problem currently use a computer for determining a solution? A rank of 10 indicates that a computer is used frequently and is nearly a necessity for solving the problem while a rank of 1 indicates little current computer usage.

Column (10) WEIGHTED TOTAL NOW: The sum of the weights multiplied by the individual ranking for all nine criterion. The figure in column 10 is a straightforward sum except for the values in column nine. If the entry in column 9 is less than 4, then the weighted value that is added to the overall sum is calculated as follows:

$$[100 * \frac{\text{entry}}{3}] - 100 = \text{weighted value.}$$

For an entry value of 3, the weighted value would be 0. For an entry value of 2, the weighted value would be -33.33. Thus the absence of current computer usage tends to greatly influence the value of the summed weighted value.

Column (11) POTENTIAL WITH COMPUTER KNOWLEDGE: Column 11 eliminates the weighting formula used in column 10 to distinguish between the levels of current computer familiarity. Therefore the values reported in column 11 represent the true weighted sum for all entry values multiplied by the respective weights.

imposing such a hardware constraint, the tasks that are amenable to expert system development tend to be tasks that are not overly complex and do not require extensive memory for program execution. The hardware constraint eliminated from consideration problems that may be appropriate for expert system development on larger machines. Nonetheless, many problems exist that are appropriate for a microcomputer-based expert system. Further, technological advances are rapidly changing the nature of the hardware constraint. Some vendors are currently selling software that allows an expert system to be created on a minicomputer, compiled, and subsequently executed on a microcomputer. Other vendors are selling enhanced expert shells and languages useful for expert systems that are engineered only for a microcomputer environment. It is likely that these trends will continue for an ever increasing range of applications. Despite the recognition of these emerging technological changes, the data in Table 7 are created with the bias of a microcomputer environment for development.

Although the problem areas identified in Table 7 were generated after discussions with Navy personnel at different locations, it may be possible that the list is not entirely representative of all problem areas or of the areas that are most important for expert system development. Creative individuals within the Navy will grasp the utility of the new technology and will develop expert systems for applications not mentioned in this report. The opportunity for such development is enormous and it is not possible to exhaustively research all potential applications. In such a rapidly changing environment, application areas seem to be limited only to the imagination of the personnel.

3.3 Candidate Applications

The applications listed in Table 7 present many opportunities for development of expert systems to be used at Navy shore facilities. Because the applications are ranked, the listings also point out areas that are inappropriate for the expenditure of funds or time. The rankings may be divided into several categories: promising, unlikely, and inappropriate. Although there are no firm numerical cutoffs for the three categories, the groupings tend to follow the following divisions:

CATEGORY	WEIGHTED TOTAL NOW		POTENTIAL WITH COMPUTER KNOWLEDGE
Promising	>50	and	>80
Unlikely	<50	or	<80
Inappropriate	Estimated Difficulty 10 (Col. 2)		

The "weighted total now" criteria refers to the judgement of the potential for an expert system by summing all of the entry values. "Potential with computer knowledge" refers to the weighted total plus a determination of the effect computer familiarity would have on the expert system application. A discussion of the candidate applications, particularly the promising applications, follows in the next several sections. There are 24 identified applications that are believed to be promising candidates for expert system development.

While many of these candidates are in the areas of fault diagnosis or design. the area with the most applications is data base analysis/management support. The concentration of applications in this latter area reflects the fact that the Navy is increasingly dependent upon large amounts of data to support the decision-making process. Because the data bases tend to be both large and often difficult to access, it is critical that management personnel have the ability to access the information in the files. Furthermore the area of data base management already has considerable computer expertise thereby facilitating the adoption of expert system technology. Each application area is discussed in the following sections.

3.3.1 Design: Buildings/Processes

The first area of discussion incorporates diverse phases of design for both buildings and utility-related processes or systems. Expert systems are believed to be powerful tools in this area because of the ability to bring together many disparate disciplines so as to guide the decision-making process. Computer-aided design (CAD) is fairly common, however symbolic computing used in expert systems offers several advantages over conventional CAD:

- Symbolic languages allow more direct representation of design concepts. These include the objects being manipulated, the rules governing their arrangement, the dependencies which link them, and the constraints which limit them.

- The expert systems methodology makes it much easier to cope with uncertainty. By definition, any design process works from a starting point where the ultimate result cannot yet be defined. It is usually necessary to strike a balance between the design objectives and the resources available. An exploratory approach is needed to find an optimal result.

- A knowledge base provides a suitable means of representing design expertise, much of which is heuristic and informal. The development of a common knowledge base can provide an important resource in itself for the user community.

For the primary candidate applications in Table 7 a short discussion of the merits and attributes for each application is provided in the following paragraphs.

Cogeneration Feasibility Analysis

Cogeneration applications have been increasingly implemented at selected Navy installations. Although cogeneration has been common among certain large industrial users for many years, recent technological advances combined with changes in electricity and fuel rates have made cogeneration potentially attractive to a wider range of shore facilities. The decision to install cogeneration capability is complex and requires inputs from several disciplines. It is believed that an expert system may facilitate this decision-making process.

Many technical factors help to determine whether or not a cogeneration installation is attractive, as well as a range of less quantifiable concerns. For example, it is important to determine hourly, daily, monthly, and annual thermal and electric requirements and process temperatures so that one may have an estimation of the total energy and thermal contributions of the facility. These are relatively straightforward calculations that follow accepted procedures. It is also necessary to determine the appropriate technology (e.g., combustion turbine, steam generation, or internal combustion engine) and required temperatures that best match the project requirements. Other areas are also important to the decision process and deserve attention. Factors such as the method of financing (e.g., third party), degree of risk aversion, perceived equipment reliability, perceived uncertainty of electric rates, federal, state, or local environmental regulations, plus space constraints all play an important role in the investment decision. No single individual can stay on top of all of the various issues, particularly for the different state and utility service territories in which Navy shore facilities are located or to the continual advances in technology.

An expert system may be designed to assist decision makers for evaluating potential cogeneration installations. It is anticipated that the expert system would contain specific engineering and economic evaluation techniques that could interact with other cogeneration analysis packages such as PC-Cube, CELCAP, and DOE2. These packages are currently used by Navy personnel. The expert system would be tailored to reflect specific Navy concerns such as on-line reliability or compatibility with existing equipment.

Energy Retrofit

Since the mid-1970's, energy efficiency in buildings has been a major concern for NAVFACENGCOM personnel. As building energy budgets grew in share of overall operating budgets, so did a concern for evaluation methods to enhance the energy efficiency of buildings. Various tools have evolved to assist Navy personnel in determining appropriate retrofit measures. Manuals, energy audit worksheets, and computerized analysis programs have all played a role in the building energy conservation program. NCEL has developed A-LESP (Navy Activity Level Energy Systems Planning Procedure) for analyzing energy conservation opportunities. Further, a sizeable number of energy auditors have been employed and trained by the Navy.

Energy-related retrofit measures continue to be important for Navy operations. An expert system for energy conservation actions is believed to be a valuable option for development. It is likely that such an expert system would increase the efficiency of the auditors, reduce the required man-hours per building per task, and help improve the overall quality of work.

The proposed expert system would complement existing energy audit activities. A suggested approach is for the system to be able to diagnose potential problem areas through analysis of fuel bills for shore facilities with sub-metering. Such an approach would compare a building with a representative "average" building and look for abnormalities in energy usage. If an energy consumption value outside of an anticipated level is found then the program would try to identify likely causes of the problem. The program would search its files for information on the building's appliance inventory, occupation profile, climate conditions, or other criteria for clues as to why energy consumption may be high and then the expert system would offer recommendations as to further action. Other approaches would be appropriate for facilities that are master-metered.

The expert system could be tied to current programs that analyze such conservation options as lighting, swimming pool covers, or solar water heating. A data base would be integrated with the expert system that would include items such as recommended insulation levels and types, window treatments, current prices for materials, and names of approved suppliers. All of the analytic procedures would be meshed with an economic analysis. Such an approach for A-LESP may be particularly useful.

In summary, the energy retrofit expert system would save considerable time and effort for the auditor. The auditor would have to collect the key energy-related data such as the appliance inventory, historical fuel records, and occupancy schedules but after that the expert system would be a valuable tool for performing the analysis of conservation measures.

Building Renovation

From the perspective of an expert system, building renovation is similar to the energy retrofit of buildings yet important differences exist in domain or knowledge-related areas. The format for a building renovation expert system would be similar to other design expert systems. The expert system would act as an aid to guide the user through the various stages of evaluating a building's condition and making recommendations for renovation activities.

The knowledge base for a building renovation expert system would consist of building and fire codes to facilitate determination of costs for renovation in a timely and accurate manner. The expert system would account for variables such as door frames, glass area and types, stairway construction, lighting and plumbing installations, and current or proposed building functions.

<u>Design of Solar Systems: Passive and Photovoltaic</u>

Solar system design for passive and photovoltaic applications offers a good opportunity for expert systems. Some of the key ingredients for a useful expert system came together nicely in this area. Typically, the design process is complex, experts are relatively expensive, and applications occur in a wide variety of situations and geographic locations. Further, accepted procedures for the engineering and economic analysis exist that may be readily incorporated. However external economic considerations somewhat obviate the need for solar design expert systems. The Navy is not heavily involved with the construction of new buildings, particularly with regard to the wide ranging retrofit and renovation programs for the existing building stock. Passive solar retrofit measures are rarely cost-effective. Therefore passive solar systems will have only a small but growing impact on Navy shore facility operations. From the standpoint of photovoltaic systems, installation costs are simply too high save for applications in remote areas. Both passive design and photovoltaic systems are beneficial technologies with a strong future in the Navy, but the design components within these areas are not prime candidates for the immediate development of expert systems.

The Navy already has a passive solar design manual, Design Procedures for Passive Solar Buildings, MIL-HDBK-1003/19 and a computer based template to accompany the manual, PDQSOL. These two tools work in concert to help the engineer or designer create a building that meets various project objectives. In order to use the design manual and PDQSOL effectively, the user must have an understanding of the various design assumptions and principles incorporated in the manual and spreadsheet. A user may easily overlook an important data input because of lack of familiarity with the design process. An opportunity exists to create an expert system front end for PDQSOL that would guide the user through all of the critical steps. Such an approach would be useful for eliminating mistakes and would also allow a user to reduce the learning time required to use the design program.

The Navy has installed photovoltaic systems (PV) to provide electric power at remote sites. Design configurations vary from site to site depending on load requirements, system efficiency, environmental conditions, and reliability demands. Economic concerns often dictate important design parameters. Computer-assisted programs such as PV Form and PV F-chart help with the design process but are limited in their applications. An expert system may be created that serves as a front end to the design programs so as to speed the design process.

It is anticipated that some of the following elements will be included in a photovoltaic design expert system. An interface to access solar insolation data base so as to determine peak and average solar radiation data. A data base of energy consumption data for a range of appliances or loads that are typical for Navy installations. The expert system would be designed to extract from the user information such as how many hours per day the load would occur.

the required reliability, the estimated life span, or economic constraints. Given the input and the knowledge base, the expert system would help determine the array size, the battery storage size, and the estimated system cost.

3.3.2 Fault Diagnosis

The diagnosis of faults in machinery and systems is a very promising area for application of expert systems. Special skills are often required for determining where a fault exists in complex equipment. Expert systems are particularly useful as technical assistants for analysis of problems in narrow, focused domains. Furthermore, there are often well established methodologies for fault analysis that can be readily incorporated into an expert system "if-then" format.

The Navy devotes considerable effort towards solving mechanical problems. Many manuals, handbooks, and training workbooks exist to help Navy personnel solve problems in operating machinery and systems. Table 7 lists sixteen different areas that pose potential problems at various shore facilities. These are representative problems and are not inclusive of all maintenance and repair operations. However, the breath of the list is illustrative of the range and complexity of problems that Navy personnel confront with budget and manpower constraints. Expert systems offer an opportunity to enhance the efficiency of delivery of services in this area. In the following paragraphs several of the candidate applications for fault diagnosis are reviewed.

Promising Candidates

Expert systems are believed to be appropriate for a host of fault diagnosis applications. A list of the candidate areas identified in Table 7 includes steam distribution, power transformers, refrigeration systems, circuit boards, photovoltaic systems, and electronic and pneumatic control systems. Each of these areas is covered by current Navy handbooks and training manuals and expert systems are likely to be good tools to complement the existing problem solution approach (see Appendix B for a list of Navy manuals and handbooks that may be enhanced with an expert system). Further, an expert system for diagnosis of faults in solar water heaters (SOLFIX) has already been developed and this system may serve as a shell for subsequent expert systems thereby greatly reducing development costs and time requirements (Gustinis, 1987).

All of the identified problem areas may utilize a generic expert system that differs only by the nature of the knowledge base. The approach for problem solving in each area is similar. Each area has reasonably complex equipment that can fail in a number of known ways. The repair of such equipment requires trained personnel who utilize a variety of formal rules and rules of thumb for assessing the nature of the problem. These rules and heuristics may be captured in an expert system to help others solve similar problems.

The diagnostician expert system would be designed to guide the user through a series of steps to determine the problem and then would recommend a remedy. The expert system could contain a data base that could be accessed for the recommended parts, if necessary, and where and how to obtain the parts.

Unlikely Candidates

Energy Management Systems

Computer-based energy management systems (EMS) have enjoyed increasing popularity over the past decade. A large number of EMSs have been installed in Navy facilities, particularly in larger building complexes. These systems allow for precise control over energy conversion and distribution equipment and offer the benefit of considerable dollar savings as well as increased comfort. EMS applications also tend to have complex failures that require specially trained personnel for repair. An expert system would be a likely candidate for this area except for three drawbacks.

First, most EMS installations are covered by a service contract with the engineering firm that sold or installed the equipment. The service contract provisions generally include the maintenance and repair of the EMS. Thus, Navy personnel are not required for this function. Furthermore, Navy training programs are not focused towards diagnosing and repair of EMS problems so there is a clear lack of qualified personnel to do the work.

A second reason that inhibits the development of an expert system for an EMS diagnostician is the microcomputer limitation. An EMS contains a large number of parts that may fail in many ways. Diagnosing the problem, while often methodologically straightforward, is difficult and requires considerable knowledge. Because of the large number of failure modes and concurrent number of rules, it is believed that a microcomputer would not be an appropriate tool for development of an expert system. Rather, a larger machine is likely to be more useful.

Another reason for exclusion of EMS applications from diagnostic expert system consideration is the wide variety of equipment. Each EMS installation is almost a unique system with its own enhancements and peculiarities. Control strategies may differ according to the types of equipment to be monitored or maintenance guidelines will vary depending on the manufacturer. The lack of standardization makes it difficult to create a meaningful expert system. A more narrow, focused problem domain is necessary, especially for the microcomputer environment.

3.3.3 Enhancing Training and Counseling Methods

Work on applying the techniques of AI to computer-aided instruction (CAI) has been going on since the late 1960s. The motivation has been to find a better alternative to conventional CAI systems. A number of projects have demonstrated that the addition of intelligence can make CAI a much more attractive proposition, but there remains relatively little commercial interest in the area. A plausible explanation is that expert instruction systems do not offer the prospect of great financial gains - with a few exceptions. Compared with the gains available from finding oil more quickly or discovering a profitable trade in the foreign exchange markets, substituting for a teacher's time is hardly worthwhile. And the cost of failing to train students properly does not appear explicitly in anyone's liabilities.

One exception is where teachers are simply not available and students, or their sponsors, are prepared to pay well to learn a valuable skill such as computer programming. Another is in training to use complex and valuable equipment, where it may be too expensive and risky to let students experiment with the real thing. The alternative to building an expensive simulator may be an intelligent program with a vivid graphics interface for the student to work with.

"Steamer," a system developed by Bolt, Beranek, and Newman for the US Naval Personnel Research and Development Center in San Diego, provides a leading example. Steamer simulates the operation of a naval steam propulsion system as an aid to training technicians. Implemented on Symbolics LM-2 equipment, it has a wide-band width color graphics interface which presents the student with interactive diagrams of the different parts of the steam system. The student can manipulate the controls and generally experiment with the simulation quite freely. A prototype Steamer was in use on a US Navy training course by early 1983, and was well received by users. Steamer requires a large machine and sophisticated software and is not appropriate for a PC AT.

Another important application of expert systems concepts in this area, intelligent CAI, is in the idea of modeling the student's own knowledge and behavior. By building up a picture of what the student does and does not know, an intelligent CAI system can decide how to guide an interactive session. Some work has also been done on identifying "bugs" in the student's thinking - systematic errors which once found can be corrected. An expert CAI system with these capabilities might be able to offer more flexible and responsive training than a live teacher in many circumstances.

3.3.4 Data Base Analysis/Management Support

The expert systems concept was born in the late 1960s with the development of software to aid scientists in the analysis of complex chemical data. Since then the idea has spread to several areas of pure and applied research, and a number of commercial expert systems packages are available to carry out data analysis task. Data analysis systems have also made an appearance as an aid to managing complexity in other problems such as troop movement, the stock market, or assessment of political risk in foreign nations.

Despite these examples, many applications of this type of system seem to be in scientific research. The significant areas include chemistry, biotechnology, mathematics, and geology. In all these sciences, expert systems are operating in domains where the scientific laws involved are well established and experts have developed powerful heuristic rules for using them, but the sheer size or complexity of the mechanics of analysis may defeat the scientist.

Every expert system uses "facts" and "rules." The former is always a data base item, the latter may be (in interpreted systems). What distinguishes data base analysis systems is only the numerical preponderance of "facts" over "rules." This has implications for the software. If large data bases are to be scanned, the computer must have very large memory and few rules for speed. The more advanced "relational data-bases" for the IBM PC AT, given 10,000 entries in the data base, may require <u>hours</u> simply to do a correlated multi-parameter search. The sheer bulk of the data becomes a serious bottleneck.

3.3.5 Software Support

There is a clear opportunity for expert systems which assist in the use of technically complex software or equipment. There is usually a shortage of expertise, and no established professional group with a vested interest in providing the skills required. Frequently it is desirable to give non-specialists access to the software of equipment so they can use it as a tool in their own work. Front-end systems which bridge this gap may range from specialized training and advisory packages to more sophisticated systems which may go a long way towards planning the use of the software and equipment and drawing conclusions about further actions.

One area emerged in our study of Navy practices that fell clearly in this domain; software support for building energy simulation models such as DOE2, PDQSOL, or BLAST. Current Navy regulations require that for each new building over 10,000 square feet the thermal performance of the building is to be modelled to minimize the long term life cycle cost for energy consumption. The thermal modelling is to be performed on either DOE2 or BLAST. Both of these models are complex and require considerable user expertise in order to fully utilize the power of the tool. An expert system can be designed to help reduce the effort required to use these models.

Key features of an expert system for a DOE2/BLAST front-end would include some or all of the following: an interface to weather data files, a data-base of specified energy conservation levels such as insulation, lighting, domestic hot water, or mechanical efficiency of HVAC equipment, and an interactive methodology for determining occupancy schedules. Each of these areas has been identified as troublesome for DOE2 users and an expert system front-end would be useful.

A major constraint exists for developing an expert system front-end for DOE2. This is a commercial product for microcomputer applications supported by a private firm. It may be more appropriate to encourage the firm to develop such an expert system front end. A clear need exists for the expert system and encouragement from the Navy may help the private development effort.

3.3.6 Real-Time Monitoring

A great deal of AI work has been concerned with "signal understanding" systems typically aiming to operate in real time. The biggest area of all is natural and spoken language understanding, which is outside the scope of this report. But language developments such as the Hearsay II system have been an important source of the programming tools and architectural ideas which are being used as the basis of real-time expert systems in other areas.

A "blackboard architecture" is the common basis of most if not all real-time expert systems. Blackboard architecture refers to a powerful technique for structuring expert systems so that they may be integrated with other types of software. This provides both a means of controlling a forward-chaining inference process, and a way of integrating data from different types of sources. The blackboard provides an effective interface between a flow of data from any source (e.g., local data bases, on-line information retrieval, physical sensors and monitors) and the knowledge base which must monitor events. Typically, incoming data is posted as a hierarchy of levels on the blackboard and monitored by a number of expert system modules called knowledge sources. The function of the knowledge sources is to draw conclusions from the data inputs at their level of the blackboard and forward the conclusions up to higher levels so that the system as a whole can achieve a wider understanding of events in the domain it is observing, and report on it, or suggest actions to its users.

Potential Navy shore facilities application areas where real-time expert systems using blackboard architecture are seen as having special value include a problem identification network and operation of power plants. The latter area, power plant operation, is an excellent area for expert systems yet is far beyond the scope of the microcomputer environment. However, special operations within a power plant may be amenable for expert systems.

A problem identification network which would convert signals from numerous sensors located throughout a facility into useful information that would detect abnormal conditions may be considered. Problem identification via electronic means with message receiving and sending capability can be accomplished for as little as $100 with commercially available equipment. However, an extensive real-time network of sensors can be quite complex and may easily exceed the capacity of a microcomputer.

4.0 EXPERT SYSTEM DEVELOPMENT

The Navy has many options for the development of expert systems. One approach is to issue a Request for Proposals (RFP) for the development of an expert system for a particular application area. This approach is common in the Navy. The contract approach has many benefits and is likely to be the preferred development method.

Another approach is to buy a ready-made expert system. Packaged expert systems are available as commercial products from a number of firms. Unfortunately the majority of applications are for financial or computer-related areas. Packaged expert systems for Navy shore facilities operations do not appear to have tapped a commercial interest as yet.

A third approach is to develop expert systems in-house. This is a useful approach because it fosters the creation of knowledgeable expert system personnel who will help lead the Navy in this growing area. It is likely that this approach will be followed for the development of expert systems for microcomputers with the help of expert system shells. Because this will be an important area for Navy personnel, a review of the stages for expert system development follows. Table 8 summarizes a four stage development process.

4.1 System Specification and Problem Determination (*adapted from Citrenbaum et al., 1987*)

The first stage, system specification and problem determination, corresponds to the requirements analysis stage in a conventional software development project. The major objective is to ensure that the project attempted will be successful in terms of both satisfying a real need and technical feasibility. The three main

TABLE 8.
Four Stage Expert System Development Methodology

I. Problem Determination and Specification: assure a useful and successful project
- Identify Candidate Opportunities
- Build on Analogous Successes
- Determine Knowledge Requirements
- Specify System Functions

II. Initial Prototype: refine requirements; quickly demonstrate technical and economic feasibility
- Select Inference Mechanism
- Select Knowledge Representation
- Use Existing Advanced Tools
- Limit Initial Scope
- Minimize Initial Use of Experts
- Determine Feasibility

III. Expanded Prototype: handle the complete problem
- Expand Use of Experts
- Utilize Rapid Prototyping
- Expand Scope of System
- Provide I/O Interfaces
- Add Bells and Whistles

IV. Delivery System: provide a performance and cost-conscious field-ready system
- Optimize Speed
- Target to Appropriate Hardware
- Customize User Interface
- Maintain System
- Provide Detailed Manual

Source: Citrenbaum, et al., 1987

thrusts are (1) to determine whether, in fact, an expert system approach is most suitable for the problem, (2) to carefully select an initial prototype subset problem so that a successful demonstration can occur relatively quickly, and (3) to discover the problem's underlying knowledge requirements so that appropriate knowledge representations and tools (such as a shell) can be brought to bear.

4.2 Initial Prototype

The major objective of the initial prototype stage is to demonstrate quickly the technical and economic feasibility of the desired expert system. An early demonstration has several advantages, especially from a management perspective, where there may be reluctance to fund a major development in a risky or unknown technology, especially where there is no history of past successes. Typically the initial prototype is concerned with only a central subset of the problem and does not provide the full range of ultimate functions. Specifically, functions such as data base interface, real-time performance, and super-intelligent user interface may be missing, but an explanation facility should be present to enhance user acceptance and validate the reasoning.

Development of the initial prototype consists of devising a suitable expert system architecture and knowledge representation. The strategy taken will depend on the depth and complexity of the problem, whether it is data-driven, the anticipated strength of inferences possible, and the extent to which sub-problems are likely to interact. Obviously, the more flexible the tool(s) used, the more responsive the design can be to subtle details of the problem. The major problems that may be encountered in this phase are completing it quickly and within a limited budget, and completing the knowledge engineering sufficiently to ensure that the essential parameters are included. Depending on the tool, the initial prototype may be completed by the domain experts themselves, although the services of specialized knowledge engineers are often recommended to avoid becoming trapped in unsuitable representations.

4.3 Expanded Prototype

Following an initial prototype demonstration of the concept and a project go-ahead, the major objective of the expanded prototype stage is to develop the full set of expert system functions required to deal with the complexity of the complete problem. The subset problem selected for the initial prototype is here expanded to the full complexity of the domain area, and the interactions with related systems such as data bases, measuring equipment, video, voice I/O, and so forth, are included. It may be reasonable to enhance the initial prototype iteratively, or to discard it (keeping the knowledge) and move to a different model; this often depends on the capabilities of the shell selected for the initial prototype. A quick-implementation shell with limited power often makes sense for the initial prototype, even though it cannot support eventual expansion. The major development problems that may be encountered in this stage tend to be technical in nature and result from the complexity and sophisticated features that are built into the system.

4.4 Delivery System

The expanded prototype may be suitable for deployment as-is where only one or a few copies are needed and where the prototype performance is sufficient for the target environment. However, in many cases an operational environment based on different hardware (e.g., a 68000 work station or microcomputer instead of a Symbolics) may be required, necessitating a re-deployment of the system. The major objective of this stage is to port the expanded prototype system to the target environment. Typically a delivery system differs from the expanded prototype in that it is widely deployed geographically (and thus must run on inexpensive hardware such as a microcomputer) and meets more stringent performance and robustness requirements. The major development problems that may be encountered in this phase result from design and function tradeoffs required to make an expert system faster, smaller, and portable.

5.0 CONCLUSIONS

Expert systems, implemented on a microcomputer, appear to have a significant potential for assisting personnel in the operations management of Navy shore facilities utility systems. Expert systems are a powerful technology that will be effectively integrated into the increasing pattern of computer usage at Navy facilities. A wide range of applications are amenable to being addressed by expert systems. Expert systems should be viewed as an additional tool to help personnel fulfill their duties and responsibilities.

Expert system technology offers the potential to enhance both the quantity and quality of work performed by Navy personnel. Increases in efficiency in terms of reduced time to perform a task and fewer errors should be anticipated. Because of the increases in efficiency, more tasks may be performed by fewer workers. This feature is especially important in an era of limited manpower and budgets. Substantial knowledge and expertise currently resides at Navy facilities. A systematic effort to create expert systems will capture this knowledge and preserve it well beyond the departure of current experts. Furthermore, the expert system knowledge base may be continually updated to reflect changes in technology and operating parameters.

The Navy environment is beneficial for the creation and utilization of expert systems. High personnel turnover rates, particularly at the maintenance level, means there is a need for continual retraining and that knowledge is lost on a frequent basis. Further, personnel who serve two or three years often do not develop significant expertise in such a short time. Expert systems will help alleviate these problems by providing expertise at a high level on a continual basis. Navy personnel are schooled in the use of manuals and handbooks and expert systems will complement this approach to problem solving. The Navy also has experience with expert systems, Steamer and SOLFIX are two examples, and this experience has been positive.

The Navy environment is also changing with respect to computer technology. There are an increasing number of microcomputers at most personnel levels and computer familiarity and skill is developing. Furthermore, the commercial market is offering faster and more powerful machines and software at prices that were once unimaginable. These machines are being purchased and used by Navy personnel for a variety of applications. Expert systems will easily fit into this environment as users begin to regard the expert system as simply another tool to help them perform their jobs.

With regard to the Navy environment, expert systems offer an opportunity to help with budget and manpower constraints. The cost to develop expert systems, particularly for microcomputer applications, will not be excessive and may be done in-house in many instances. The expert systems should help to control operating costs by allowing for the faster execution of jobs with fewer errors. This, in turn, will help ease the strain on manpower constraints because fewer people will be able to accomplish more in a given period of time.

Expert systems should find a good home for some applications at Navy shore facilities because of the nature of current operations. For instance, fault diagnosis of complex machinery or data base analysis of large sources of information are areas in which the Navy commits considerable time and effort. These are not new problems. Rather, expert systems are a new tool for helping to assist in the solution of problems in these areas.

The technology concerns, both hardware and software, are probably not critical to the use of expert systems by the Navy. It is not at all clear if there is a "best" programming language for AI applications. Each programming language has its features and drawbacks and none appear to be the overwhelming candidate of choice for all applications. Rather, some applications will be developed in C, some in Prolog, and others in LISP or another language. The language choice may well be due to the preferences of the programmer. Indeed, the increases in programming efficiency with "AI languages" will lead to more conventional programming areas being written in the AI languages. Further, expert system shells are gaining popularity and may be used by non-specialists with surprising ease. Undoubtedly some Navy expert systems will be developed on shells in-house as a solution to immediate problems.

Microcomputers do not seem to be a severe constraint, particularly with respect to the 32 bit machines that are now being introduced and commercial enhancements to existing machines that increase size and speed. Fairly large programs that address complete problems may be written for these machines. The machines are inexpensive enough that they will be relatively widespread throughout the Navy in a number of years. Thus the delivery vehicles will most likely be in place for the expert system software. Compatibility between machines should not be a problem because the great majority of Navy purchases are for MS DOS machines.

Despite the potential benefits of expert systems, drawbacks exist that should be noted. Expert systems will have their niche but should not be applied outside of the niche. For example, expert systems will not provide simple solutions to complex problems. Further, areas such as automatic knowledge acquisition will not be possible despite much media attention. It will not be possible to capture knowledge without programming. These limitations are real but are not sufficient to dispel arguments in favor of expert systems.

The initial expert system(s) may not succeed for a number of reasons. The number of rules may be limited thereby effectively reducing the scope of knowledge. Explanation facilities may be weak and thereby obscure the reasoning process. The processing speed may be insufficient for some tasks. Slow speed of execution may cause a user to seek alternative problem solving means. The potential for failure will be high if training is inadequate and the problem definition is fuzzy. Management commitment will be a key ingredient to the ultimate success or failure of the venture.

A prime concern for Navy management should be with implementation issues, particularly with respect to the fault diagnosis area. Maintenance personnel who are responsible for repairing machinery are often unfamiliar with computers and may feel uneasy relying upon the machines as diagnostic assistants. Because expert systems can make mistakes, provide incomplete answers, and may not have the depth of knowledge of a human expert, it will require patience and some tenacity to have expert systems fully accepted as useful tools. Building confidence in the users will be a critical effort that must not be overlooked.

In a similar vein, expert systems may be developed by programmers who do not interact with the end users of the tool. In such a situation the quality and utility of answers will often be disappointing to the users. Care must be exercised to solicit input from the users in the early phases of development. One approach is to specify the minimum acceptable performance that will allow the system to be considered a success.

A practical problem will exist for the delivery of knowledge in some situations. For field personnel, using a computer may be awkward or not possible. Even the powerful, portable microcomputers will not be carried to all site locations and a van- or truck-mounted unit may be parked too far away to make practical use of the computer. Power failures may render useless the expert system designed to help locate and repair the source of the power failure. However, critical applications could either use a portable PC or install an uninterruptible power supply.

One final note of caution should be expressed with regard to the actual creation of an operable expert system. Even though expert systems may be developed with relative ease, a certain level of skill is required for programming. The lack of experienced programmers within the Navy may slow the development process. Management should understand that expert system programming requires some areas of knowledge that the current staff may not possess. The skills may be developed with time but system development expectations should not be unrealistic.

Expert systems should be viewed as powerful tools that can provide useful information in a timely manner for specified areas. Expert systems must be allowed to evolve over time to reflect both changes in technology and in the knowledge base. The Navy may realize increases in the efficiency of some O&M services for modest budget expenditures with the adoption of expert systems in appropriate areas.

6.0 RECOMMENDATIONS

It is recommended that NAVFACENGCOM proceed with the development of expert systems for utility operations at shore facilities. Substantial benefits will accrue to the Navy with the successful implementation of expert systems throughout the diverse areas of shore facility management. In an era of increasing technological sophistication, limited budgets, and manpower constraints, expert systems will be one tool that the Navy may utilize to increase its operational efficiency. A well defined program of action will help the Navy achieve the potential for expert systems.

The first step for NAVFACENGCOM should be to identify the Navy goals for the use of AI techniques. Such goals should be broad in purpose yet specific enough to give direction. Some suggested goals include the following:

- The NCEL will develop expert systems for utilities operations for microcomputer deployment.
- Select several target shore facilities to utilize the expert systems developed by NCEL.
- After a trial period the expert system program will be evaluated to determine its successes and failures.

To achieve the Navy goals, a several step process is recommended. First, it will be important to select the domains for expert systems. From the results of the work in this report, it is recommended that development funds and effort be directed towards the areas of fault analysis, data base management, and design of buildings/processes. These areas are found throughout the Navy and may be readily identifiable. For fault analyses, expert systems should be developed for diagnosing regular maintenance problem areas. Recommended targets of opportunity include: steam distribution, power transformers, refrigeration systems, circuit boards, photovoltaic systems, and pneumatic and electronic control systems. Training books exist that can be used as templates for the knowledge base as well as a number of experts within the Navy. A model diagnostic expert system for solar water heaters has already been developed for NCEL and this system may be adapted by altering its knowledge base for other application areas. Because of the existing in-house skill and experience, development should be rapid and not expensive.

The design process for buildings or processes is another area that the Navy should consider for expert system development. One application, analysis of cogeneration feasibility, has particular merit. The expert system, in concert with the CELCAP program, would serve as a disinterested third-party auditor that would evaluate the feasibility of cogeneration proposals. Because the Navy has a considerable investment in buildings, the care and maintenance of these buildings deserves special attention. an energy retrofit or a building renovation are complex activities that involve many disciplines and large information requirements (e.g., materials specifications, engineering requirements, and code requirements). Expert systems will help organize the workload and speed the delivery of a final product for personnel in these areas. Another design process of special interest is the design of passive solar buildings. Energy costs will continue to rise at some unknown rate and the Navy is committed to efficient building design and operation. Passive solar buildings will save the Navy substantial operating funds over time. An expert system that helps to capture the critical passive solar design features will ensure an efficient building design.

Data base analysis is the third recommended domain for expert system development. The Navy collects vast quantities of data and much is currently included in sophisticated data files. A problem that is beginning to occur is that management cannot access the data because of the special skills and knowledge required to make use of the data bases. Expert systems may be designed to ease these problems. This area could have enormous implications for increases in the efficiency of management time.

Upon the selection of the appropriate domains and applications, the Navy should train (hire) staff in AI fundamentals. Training in AI techniques may be acquired via lessons from a vendor. This approach will lead to the development of a skilled core group with important AI knowledge that can subsequently be disseminated throughout the shore facilities.

With the skilled staff, and, initially outside contractors, prototype systems should be built. The prototypes should be small with all of the features of a fully developed system. This approach will encourage rapid development so that a decision may be made as to whether or not it is worthwhile to proceed with a particular application. The prototype should be carefully evaluated as to its effectiveness (i.e., does it address the central problem? Can it address the central problem?), its coverage (i.e., what is the required knowledge that is necessary?), and its potential now that some work has been done. Potential should be defined in terms of the potential number of users, the estimated dollar savings, or the estimated reduction in time required to perform a task. Evaluating the potential of a prototype will be difficult but it must be done.

The evaluation of the prototype may be done by distributing the expert system to two or three shore facilities for trial use. While this approach will give important "real world" information, care must be exercised that the users have sufficient training in order to use the tool. The training component cannot be overemphasized because it is the user who will ultimately determine the effectiveness of the tool.

In summary, the Navy should choose a problem from the defined application areas. The problem should have a high payoff potential, be limited in scope, (i.e., have few rules), and be useful as an assistant. Evaluation criteria should be established and a time frame identified. A tool should be used that is consistent with the particular problem domain. Training from a vendor in AI techniques may be desirable. The system should be implemented on a small scale to test its effectiveness.

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APPENDIX A

NOTES TO TABLE 7

NOTES TO TABLE 7

As shown in Table 7, the nine evaluation criteria are weighted so as to make some criterion more important than others. For instance, the determination of task difficulty is assigned a weight of four while the cost of expertise, column six, is weighted by two. This indicates that the task difficulty is considered to be twice as important as the cost of expertise when assessing the applicability of an expert system. Each of the tasks as similarly ranked to reflect subjective judgement on the relative importance of each criterion.

Task difficulty is the most heavily weighted judgement criterion. Determination of the difficulty of the task refers to how hard a task is to perform for a human expert. This is a critical consideration because this determination will eliminate trivial problems and will also identify problems for which a true expert is required. The task difficulty determination is also the most heavily weighted criterion because it is believed that the distinction of difficulty defines the extent to which a problem requires expertise for its solution.

The second criterion, column two, refers to the programming difficulty. It is closely linked to the determination of the task difficulty for a human expert. We assume that a difficult problem also becomes more difficult to program, especially on a microcomputer. The weighting factor is a negative two which indicates that the more difficult the problem, the less likely it is amenable to an expert system implemented on a microcomputer. This weight becomes very significant after a rank of eight is assigned in column one. For a rank of eight or greater the corresponding value in column two is increased by a factor of nearly twenty, thereby effectively diminishing the total summed weight in column ten by a proportionate amount. The reason for such a severe weighting formula is to allow for distinction between problems that are addressable for a microcomputer and those problems that are best reserved for larger machines, or not to do at all

An expert system is often valuable if it can offer a solution to a problem that is critical to the operation of the facility. Thus in column three a determination is made of the urgency of solving the problem in an expedient manner. For example, do day-to-day operations depend on the solution to the problem or do lives depend on a solution? The varying degrees of urgency are considered but not from an emergency perspective. Emergency conditions are considered abnormal and are not included in the ranking.

Expert systems are particularly useful if there is a repetitive problem or issue that occurs in many places. In column four an attempt is made to determine the frequency of problem occurrence. The typical solution to these problems is to have many experts or to try and let the problem slide until an expert can be found. The great portability of an expert system allows it to be in many places at once, thus freeing demands on a human expert and allowing for the timely solution of a problem. A high rank in this category indicates that a problem is common and therefore an expert system may be an appropriate tool.

Knowledge bottlenecks occur with the loss of human expertise. A long term Navy problem is the high turnover rates of personnel who take valuable knowledge with them when they leave. In column five a determination of the extent to which expertise is being lost is included. An expert system provides value because expertise does not have to be lost upon the departure of the resident expert. Rather, the expert's knowledge may be preserved and continually updated for others to use.

The cost of human expertise, column six, influences the extent to which one utilizes the services of an expert. Outside of emergency conditions, high cost experts are not used until their services are truly required. An expert system is effective at reducing long run operating costs even through initial development costs may be high. A user may feel it easier to rely upon the expert system because of its low operating costs and its ability to provide useful results.

For the development of an expert system, it is useful to define a problem area that has an accepted problem solving approach. In column seven, a determination is made as to whether an agreed upon methodological approach is appropriate for the resolution of the problem. The accepted approach makes for an easier creation of the expert system and lends credibility to the answers and recommendations provided by the expert system. While a systematic methodology is useful, its not a critical determinant of expert system applicability and therefore this criteria was weighted with only a value of one.

In column eight, a determination is made as to whether a problem can be isolated from other problems. Separation and isolation of the problem area allows for the creation of a more specific expert system that does not attempt to solve all problems. It is essential that the expert system be designed so as to limit its scope. By focusing on an easily distinguishable problem area, the expert system has increased utility to the user and is easier to develop.

Computer usage by problem solvers gives an indication as to the types of tools currently used for solving the problem. Usage of a computer by current problem solvers suggests that a problem area is amenable to being addressed by computer-coded instructions. This approach augers positively for the adoption of an expert system for enhancement of the problem solving process. The formula in column nine substantially affects the final result in column ten. For rankings of less than four, which indicates little current computer usage, the formula reduces the relative value by a factor of three, thereby strongly indicating the significance of computer usage on the applicability of an expert system.

In columns ten and eleven the summed weighted totals for each problem area are presented. Column ten shows the current value of the sum of the weights multiplied by the individual entries while column eleven shows a similar summation that suggests the potential for an expert system if the current problem solvers used computer technology. For many problem areas, particularly in fault diagnosis, there is little current computer usage and this fact is reflected in the difference between columns ten and eleven.

APPENDIX B

NAVY MANUALS AND HANDBOOKS:
EXPERT SYSTEM ADOPTION

NAVY MANUALS AND HANDBOOKS: EXPERT SYSTEM ADOPTION

The Navy issues and updates many handbooks and manuals for the operation of its shore facilities. In addition, manuals for personnel training have been developed for the Navy in specific areas of facility management, mechanical and electrical engineering, and entomology. Many of these manuals and handbooks are concerned with design processes or the diagnosis and subsequent repair of faults in machinery. Expert systems may enhance the value of the existing manuals and handbooks by providing a computerized means to access the knowledge stored in the books. The following list shows the manuals and handbooks that may be supplemented with an expert system.

Some manuals, notably manuals MO-205, Vol. 1-5, Central Heating and Steam Electric Generating Plants, are not included. These manuals are too complex for an expert system implemented on a microcomputer. Other manuals such as MO-100, Vol. 1-4, Natural Resources, were omitted because of a lack of specificity. Some manuals were not included because their publication is outdated and has been superseded by technological changes. For example, MO-119, Building Maintenance - Gallery Equipment, was published in 1963. A final group of manuals was not included because it was believed there were few users. MO-125, Military Custodial Services Manual is an example of the latter category.

POTENTIAL EXPERT SYSTEMS

MAINTENANCE AND OPERATIONS MANUALS

NUMBER	YEAR	TITLE
MO-104	78	Maintenance of Waterfront Facilities
MO-109A	72	Maintenance Manual for Antenna Groups
MO-110	81	Paints and Protective Coatings
MO-111	63	Building Maintenance--Structural
MO-111.1	85	Inspection of Wood Beams and Trusses
MO-113	74	Maintenance and Repair of Roofs
MO-114.V1	64	Building Maintenance--Plumbing
MO-114.V2	64	Building Maintenance--Heating
MO-114.V3	64	Building Maintenance--Ventilation
MO-116	72	Electrical Interior Facilities
MO-117	81	Maintenance of Fire Protection Systems
MO-200	79	Facilities Engineering--Electrical Exterior Facilities
MO-201	63	Operation of Electric Power Distribution System
MO-202	68	Overhead Power Lines--Electromagnetic Interference Handbook
MO-203.V1	63	Wire Communication and Signal Systems Maintenance
MO-203.V2	63	Step-by-Step Dial Central Office Equipment

NUMBER	YEAR	TITLE
MO-203.V3	63	Basic Maintenance Practices; All Relay Dial Central Office Systems
MO-206	64	Operation and Maintenance of Air Compressor Plants
MO-207	66	Operation and Maintenance of Internal Combustion Engines
MO-209	66	Maintenance of Steam, Hot Water, and Compressed Air Distribution Systems
MO-210	84	Maintenance and Operations of Water Supply Treatment and Distribution Systems
MO-212	82	Operation Maintenance of Domestic and Industrial Wastewater Systems
MO-220	70	Maintenance and Operation of Gas Systems
MO-304	72	Utilities Systems Analysis
MO-307	81	Cathodic Protection Systems Maintenance
MO-310	71	Military Entomology Operation Handbook
MO-324	84	Inspection and Certification of Boilers and Unfired Pressure Vessels

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